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FINAL REPORT

Heatwaves in Victoria: A Vulnerability Assessment

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Executive summary

Victoria's Climate Change Adaptation Plan 2017-2020 lays out the approach the Victorian Government is taking to support business and communities deal with the challenges of climate change. The approach emphasises integration of climate change considerations into mainstream sector plans and planning processes.

The Victorian Government is undertaking a series of vulnerability assessments looking at different climate hazard events. This study is the vulnerability assessment for heatwave hazards to better understand:

- The nature and extent of heatwave vulnerability for key sectors of the Victorian economy.
- The distribution of heatwave vulnerability across regional areas.
- The importance of sectoral and geographical vulnerabilities for the broader Victorian economy.

The methodological framework used in this study is an adaptation of the United Nations and World Bank 'Damage and Loss Assessment (DaLA)' methodology. The methodology adopted is outlined in detail in Section 3 of this report. We particularly focus on the vulnerability of the economy as measured by value added within a national accounting framework. Climate parameters for multiple time periods are assessed under different emissions scenarios for three severities of events - severe, extreme, and very extreme. Economic vulnerability is then assessed against the current economic structure for Victoria and across the 10 Regional Partnership Boundary Areas.

Key results

The total impact of severe, extreme and very extreme heatwave events is estimated to be $131 million (0.04% of GSP), $291 million (0.09% of GSP), and $1,000 million (0.31% of GSP) respectively. The relative sectoral contribution to each of these aggregate impacts is illustrated in the figure below.

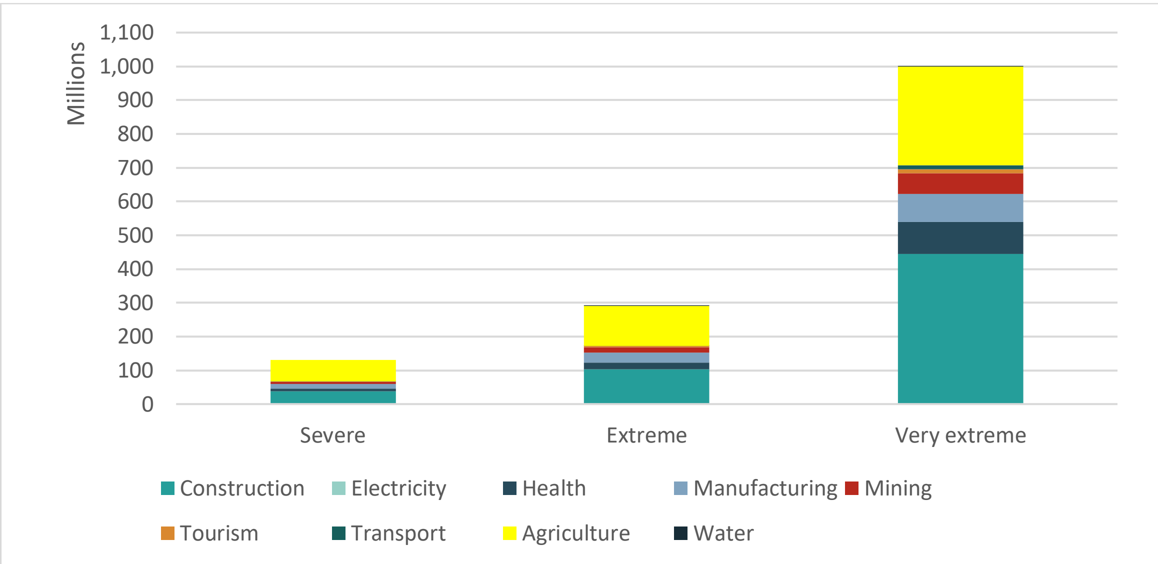

Figure ES1. *Aggregate impacts for each heatwave event modelled (sector analysis)*

Key points to note are:

- For severe level heatwave events, almost half of total impacts are from the agriculture sector. The construction sector is also a major contributor, facing almost a quarter of the total impacts. The manufacturing, health and mining sectors also face significant impacts.

- For extreme and very extreme heatwave events, the impact on most sectors is relatively unchanged. The key differences pertain to the agriculture and construction sectors. Agriculture and construction both make up approximately a third of total impacts for extreme heatwaves. For very extreme events, the construction sector experiences almost half of all impacts whilst the agriculture sector accounts for around a quarter of all impacts.

- The environment sector, and its contribution to other sectors, was not quantitatively assessed but is expected to be highly vulnerable to heatwave.

To get a better sense of the importance of the impact of heatwaves, it is helpful to consider impacts alongside the likelihood of the given (intensity) events occurring. This gives a picture of the overall level of (heatwave) risk at play. The table below summarises annual expected impact, or risk, of each heatwave category level and how this is calculated.

Table ES1. Annual 'expected' impact from each of heatwave category levels

	Likelihood for current period, Victoria average (return period)	Absolute Aggregate impact ($Millions)	Annual 'expected' impact ($Millions)
'Severe'	Once every 2 years	131	66
'Extreme'	Once every 25 years	291	12
'Very extreme'	Once every 110 years	1,000	9

A key insight from these results is that, even when likelihoods are factored in, the 'expected' impact from heatwave events is substantial. Every year, on average, the loss from heatwave events is in the order of 0.025 per cent of GSP – based on current climate and the economic structure of Victoria.

When climate change is considered, the situation changes somewhat into the medium (2030) and longer term (2050) future - as the likelihoods of each of these events increase. The table below summarises annual expected impact from each of heatwave category levels in future time periods - assuming vulnerabilities remain at their current levels.

Table ES2. Annual 'expected' impact from each of heatwave category levels for future periods

	2018 Annual 'expected' impact ($Millions)	2030 (RCP 8.5) Annual 'expected' impact ($Millions)	2050 (RCP 4.5) Annual 'expected' impact ($Millions)	2050 (RCP 8.5) Annual 'expected' impact ($Millions)
'Severe'	66	132	146	174
'Extreme'	12	23	25	33
'Very extreme'	9	24	24	39

A key insight from these latter results is that – if nothing is done to reduce vulnerabilities – overall heatwave risk substantially increases in the future under the effects of climate change.

The aggregate impacts are not evenly distributed across geographical areas. The figure below shows distribution of impacts as a percentage of Gross Regional Product (GRP). In contrast to absolute impacts where Melbourne is most vulnerable, these results show the Mallee, Wimmera/Southern Mallee, and Goulburn areas as the most proportionately affected by heatwaves. These regional economies have a high dependency on the agriculture sector.

Melbourne is proportionately much less affected, and is in fact the lowest out of all regions in the State. This reflects a more diversified and less agriculture-intensive economy for that (mostly metropolitan) region.

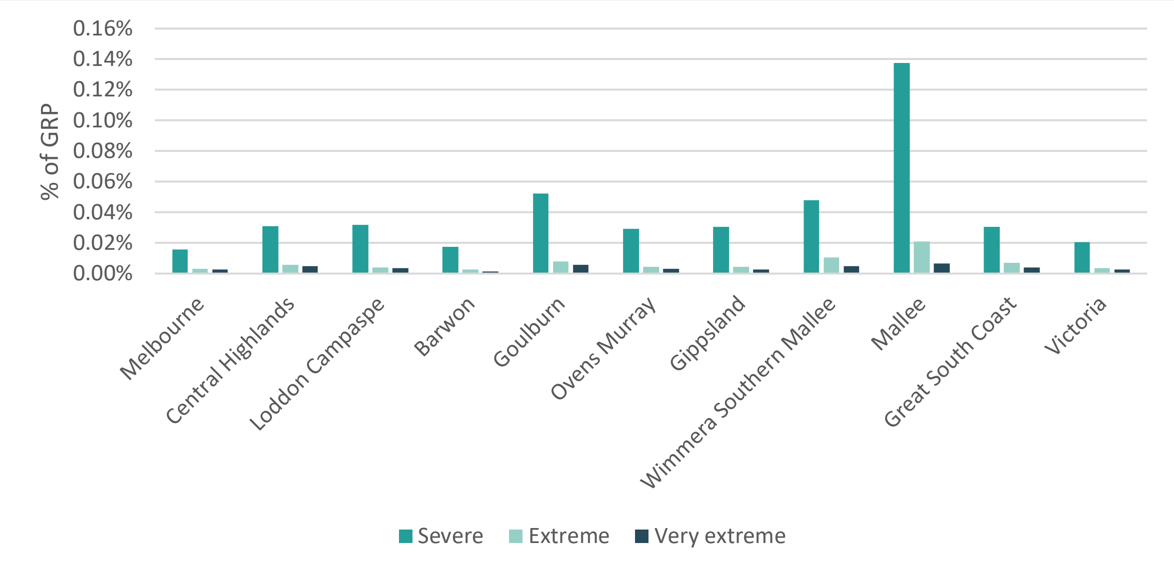

Figure ES2. *Annual expected impacts as a % of Gross Regional Product (GRP)*

Priorities for future heatwave adaptation policy effort

The analysis documented in this study provides an **overview** of the extent of heatwave vulnerability in Victoria and how this is spread across sectors and geographical areas. The analysis further provides some insight on the inter-linkages between sectors and how this plays out to influence heatwave vulnerability in other sectors (refer to sector chapters in Part C of report).

Sectors and geographical areas that are most vulnerable **and/or** which strongly contribute to vulnerability in other sectors are where the heatwave 'problem' is considered greatest. These are the sectors where adaptation policy effort by the Victorian State and Local Governments should be prioritised over the next two years.

Based on these criteria the agriculture, construction, health, environment, and electricity sectors are assessed as the highest priority sectors for heatwave adaptation policy effort. Addressing these priority sectors will also have positive impacts on vulnerability in other sectors (e.g. addressing energy service reliability will mitigate the vulnerability of the water sector).

Within the sectors that have been identified as high priorities, it is recommended that policy effort focus on addressing key barriers that are constraining sectors' capacity to adapt to changing heatwave hazards. These barriers can be thought of as the causes and drivers of the heatwave vulnerability problem.

This study has undertaken a brief desktop analysis of barriers as a starting point for future policy analysis work (refer to sector chapters in Part C). Next steps can build on this, undertaking further primary research as needed.

Importantly, this study also identified some barriers that are cross-sectoral in nature. These barriers appear to have received little attention within the traditional sector policy domains and will require increased coordination and collaboration across agencies to effectively address.

Other issues

This project is based on readily available climate, impact and economic data. It should be noted that this data is extremely limited for most sectors, necessitating the use of assumptions and surrogate measures to underpin much of the quantitative assessments presented throughout this report. The quantitative estimates should be considered indicative, and a means to understand the broad materiality and relative distribution of economic vulnerability to heatwave events.

As Victoria's approach to climate change adaptation matures, and modelling and monitoring improves, the quality of data available as inputs to vulnerability assessments will improve, and more confidence in quantitative estimates will be warranted.

In addition, data availability has also limited the scope of the quantitative assessments. Therefore, the estimates presented in this report will generally be underestimates of overall economic vulnerability.

An observation from the conduct of this study is there is very little monitoring and evaluation of heatwave risk (or climate-risk generally) being performed by State and Local Government Agencies as part of the implementation of normal policies and plans. As a result, there has been minimal learning by Government over the last 5 to 10 years about the heatwave risks and how best to modify the design of policies (if at all) so they are resilient to heatwave hazards and thus more effective at achieving their intended objectives. This is a key area for improvement.

For all sectors assessed in this study, it is recommended that integration of heatwave risk into mainstream monitoring and evaluation be considered as a practical and effective entry point to mainstream climate risk considerations into policy making and decision-making processes. Amongst other things, monitoring data should provide for a more detailed sector impact analysis following future heatwave hazard events.

1 Introduction

1.1 Victoria's Climate Change Adaptation Plan: 2017 to 2020

Victoria's Climate Change Adaptation Plan 2017-2020 (the Adaptation Plan) lays out the approach the Victorian Government is taking to support business and communities deal with the challenges of climate change. The approach outlined emphasises integration of climate change considerations into mainstream sector plans and planning processes – so that sectors are resilient to climate events and thus more likely to be effective at achieving their intended (sectoral development) objectives.

To help inform adaptation planning efforts, the Victorian Government is undertaking a series of vulnerability assessments looking at different climate hazard events.

This study is the vulnerability assessment for heatwave hazards.

1.2 Objectives of this assessment

The objective of this study is to assess the vulnerability of key sectors of the Victorian economy to heatwave events. The intention is that the study will help focus (heatwave related) adaptation policy effort over the next two years.[1]

More specifically, the study aims to better understand:

- The nature and extent of heatwave vulnerability for key sectors of the Victorian economy.
- The distribution of heatwave vulnerability across regional areas.
- The importance of sectoral and geographical vulnerabilities for the broader Victorian economy.

The target audience of this study is State and Local Government policy makers and planners of Victoria.

The remainder of this document is organised into four parts as follows:

- Part A firstly provides some background information on heatwave events along with a brief explanation of key concepts and terminology used in this assessment. It then describes the methodology that has been followed to assess vulnerability in the Victorian heatwave context.
- Part B reports the aggregate results and shows how impacts are distributed across geographical areas.
- Part C provides some more detailed information on the assessments undertaken for each of the sectors.
- Part D provides some summary analysis and outlines priorities for future (heatwave) adaptation policy effort.

[1] With a view to develop targeted sector Adaptation Action Plans (AAPs).

Part A Context and approach

2 Context

2.1 Heatwave hazards in Victoria

In Australia, a heatwave is defined as a period of at least three days where the combined effect of high daytime maximum and overnight minimum temperatures (daily mean temperature) is unusual within the local climate (BoM 2017; Nairn and Fawcett 2013).

Climate change is markedly changing the heatwave hazards experienced in Victoria. As illustrated in Figure 1, a relatively small shift in global average temperature (i.e. 0.85°C since 1880 (IPCC 2013)) has substantially changed the probabilities of extreme temperature events occurring`. Heatwaves are now becoming hotter, longer, more regular and occurring earlier (Steffan et al. 2014).

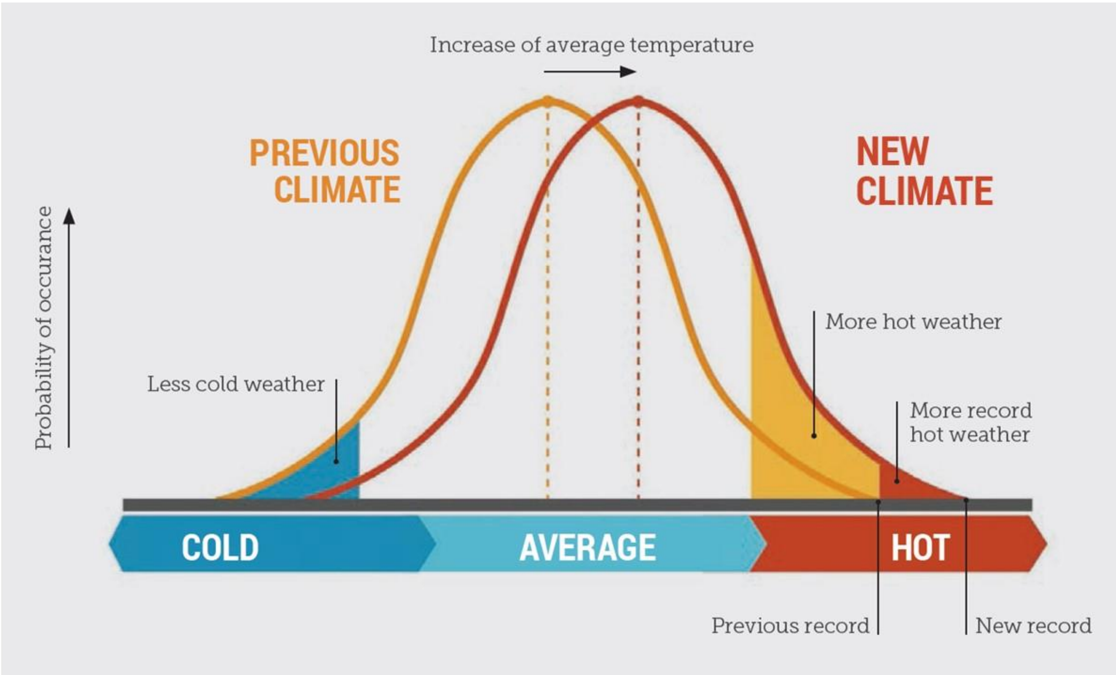

Figure 1 Relationship between average and extreme temperatures, showing the connection between a shifting average under climate change (New Climate in diagram) and the proportion of extreme events (Source: Steffan et al. 2014.)

In Victoria, the two worst heatwaves on record have occurred in the past 10 years; January/February 2009 and January 2014. In the 2009 event, Melbourne recorded three consecutive days over 43°C, while Mildura recorded 12 straight days over 40°C. The January 2014 heatwave event again broke heat records with Melbourne recording four consecutive days over 41°C and night time temperatures recording the third highest on record at 28.6°C.

These changes are impacting on a wide range of economic activities and communities in diverse ways – and are expected to further impact into the medium and longer-term future. However, the full nature and extent of vulnerability to these impacts, and how best to reduce them, are in not yet well understood.

2.2 Key concepts and terminology

There is no consensus on the concept of (climate change) **vulnerability** (ECLAC 2003, Cardona et al 2012). For the purposes of this assessment, a broad interpretation of vulnerability is taken - in line with the definition outlined in the *Victoria Climate Change Adaptation Plan: 2017 to 2020.* Here, vulnerability will be assessed as the extent to which key sectors are impacted by heatwave events.[2]

The standard risk framework is useful to help understand vulnerability. Box 1 describes this equation.

*[Heatwave] **risk** = **Likelihood** (of heatwave **event** occurring) × **Consequence** (of heatwave **event**)*
where consequence is a function of **exposure**, **sensitivity** (and **adaptive capacity)**

Box 1 Heatwave risk equation[3]

Vulnerability can be thought of as the 'consequences'[4] component of the standard risk equation. To this end, vulnerability encompasses each of the concepts of exposure, sensitivity, and adaptive capacity.

Exposure is "the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected" (DELWP 2017). Note, exposure is also sometimes referred to as the 'elements at risk'.

Sensitivity is the degree to which exposed values (people, assets, activities etc.) are affected from a given event. Another term often used in place of sensitivity is 'susceptibility'.[5]

Adaptive capacity is "the capability of a system, sector or social group to adjust to climate change, to minimise harm, to act on opportunities, or to cope with the consequences."[6] Adaptive capacity is commonly understood to be a sub-set, or determinant, of the level of exposure and sensitivity.

Another concept which is important to understand is **climate change uncertainty**. In the medium to long term future, the forecasted likelihoods of heatwave events occurring are expected to change due to climate change. However, the extent of this change is not precisely known. That is, the 'likelihood component' of the standard risk equation in the medium to long term are uncertain. This matter is discussed further in section 3.2.

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Cardona, O.D, M.K. van Aalst, J. Birkmann, M. Fordham, G. McGregor, R. Perez, R.S. Pulwarty, E.L.F. Schipper, and B.T. Sinh, (2012) Determinants of risk: exposure and vulnerability. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108. Available at http://www.ipcc.ch/pdf/special-reports/srex/SREX-Chap2_FINAL.pdf

ECLAC (2003) Handbook for Estimating the Socio-economic and Environmental Effects of Disasters, Available at http://repositorio.cepal.org/bitstream/handle/11362/2782/1/S2003701_en.pdf

[2] The *Victoria Climate Change Adaptation Plan: 2017 to 202* defines vulnerability as "the degree to which a system, sector or social group is susceptible to **adverse effects** of climate or weather events".

[3] The *Victoria Climate Change Adaptation Plan: 2017 to 2020* defines risk as "the chance of something happening that will have an impact on an objective, system, sector, asset, activity or community. A risk is often discussed in terms of the **event** (for example, a weather event or climatic change), the **consequence** of the event (positive or negative), and the **likelihood** it will happen" (DELWP 2017).

[4] It is helpful to also be aware that there are other terms that are often used in place of "consequences". These include "impacts", "adverse effects", and "damages and losses".

[5] The concept of vulnerability is also often understood to be the same as sensitivity (IPCC 2001, Cardona et al 2012). However, there is no consensus on the concept of (climate) vulnerability (Cardona et al 2012).

[6] *Victoria Climate Change Adaptation Plan: 2017 to 2020.*

IPCC (2001) Working Group II: Impacts, Adaptation and Vulnerability, Chapter 18: Adaptation to Climate Change in the Context of Sustainable Development and Equity, Available at http://www.ipcc.ch/ipccreports/tar/wg2/pdf/WGII_TAR_full_report.pdf.

Nairn J and Fawcett R (2013) Defining Heatwaves: Heatwave defined as a heat-impact even servicing all community and business sectors in Australia. CAWCR Technical Report, No. 060. CSIRO and Australian Bureau of Meteorology, p 96.

Steffan, W., Hughes, L. and Perkins, S. (2014), Heatwaves: Hotter, Longer, More Often, Climate Council of Australia.

3 Methodology and approach

3.1 Methodology

Overview

There is no universally accepted methodology for assessing vulnerability to, or the (economic) impacts of, natural hazard events (Pelling et al 2002, Carvello and Noy 2010). Estimating the impacts of natural hazard events is complex, with variations by the type of hazard (Loayza et al., 2012), limited data availability (Rolfe et al 2013), problems inherent in apportioning out a subset of consequences to a particular geographic area or period of time (Rolfe et al 2013), and further confounded in some cases by the positive impacts of weather events and reconstruction activities (Baade et al 2007, Loayza et al 2012).

The methodological framework used in this study is an adaptation of the United Nations and World Bank 'Damage and Loss Assessment (DaLA)' methodology (ECLAC 2013). The DaLA method is a globally recognised framework that has been used to assess the (ex-post) impacts of a wide range of natural disaster events (e.g. flood, cyclone, drought) in many countries. The DaLA has been also used as a framework to understand impacts of future natural hazard events and future risk (e.g. Fructuoso 2007).

Underpinning the method is a robust conceptual framework which, amongst other things, classifies impacts as either (i) destruction (total or partial) of physical assets [i.e. "damages"], and (ii) subsequent changes or modifications to economic flows in the affected area [i.e. "losses"]. Measurement of impacts are undertaken following a systematic, bottom-up (i.e. sub-sector level) approach. Impacts are then aggregated in line with the system of national accounts to provide a picture of overall impacts.

As much as possible, the method uses national accounts and statistics as the data to assess economic damage and loss. Where necessary, it also uses quantitative data derived from relevant government agencies and stakeholders, maps, surveys and a variety of other sources.

Adaptions have been made to this methodology to make it suitable for an ex-ante analysis in the Victoria heatwave context. The key adaptions are:

- To run the impact assessment for three different heatwave events – differing in intensity level.[7]
- To develop basic sensitivity functions (or basic stage-loss curves) to approximate the relationship between heatwave event intensity and impacts on economic flows.

The analysis is for current economic conditions and populations. This is considered appropriate given the substantial uncertainties associated with modelling future economic activities and that the intention for this study is to inform short-medium term adaptation planning. Climate change is considered by examining how the likelihood (or return period) of the three different heatwave intensity events modelled are expected to change by 2030 and 2050 under different emissions scenarios – to provide insight about future heatwave risk and hence the importance of vulnerability.

The methodology also includes an additional qualitative analytical step to explore the barriers constraining sectors (and households/businesses/players within that sector) capacity to adapt to changing heatwave hazards. This is a key way in which the adaptive capacity dimension of vulnerability will be assessed in the analysis. The approach taken here is broadly consistent with the Productivity Commission's 2012 Inquiry Report *Barriers to Effective Climate Change Adaptation*.

[7] These were:

- A 'severe' heatwave event with a current (average for Victoria) return period of once every 2 years.
- An 'extreme' heatwave event with a current (average for Victoria) return period of once every 25 years.
- A 'very extreme' heatwave event with a current (average for Victoria) return period of once every 110 years.

More information on each of these heatwave events are outlined in in section 3.2 below, along with details of how their likelihood of occurrence (in terms of return period) is expected to change in the future under the effects of climate change.

Step-wise procedure
The methodology for the Victoria heatwave application can be described as several specific steps. These steps are generic and were performed for each key sector.

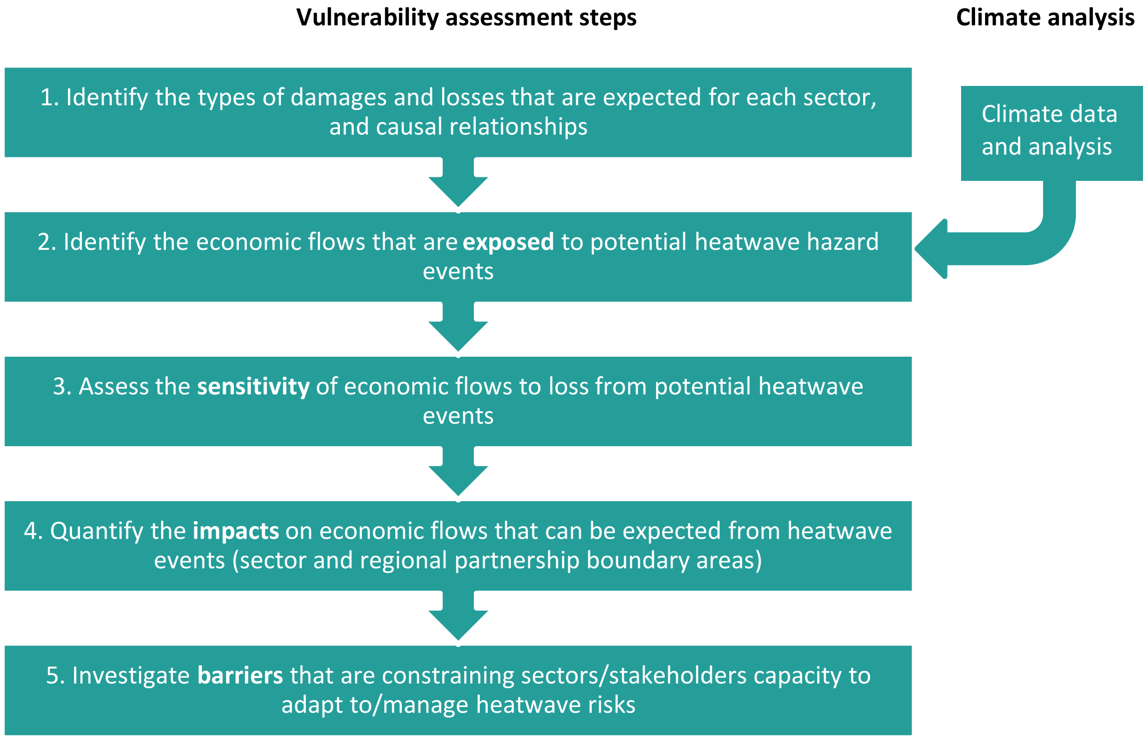

Figure 2 Generic step-wise procedure

More information relating to each step of the generic step-wise procedure is outlined in turn below:

Step 1: Identify the types of the damages and losses that are expected, and causal relationships
Step 1 identified the types of damage and loss that are expected from heatwaves for each sector. This involved (i) reviewing the types of damages and losses normally assessed under the DaLA methodology; (ii) a brief literature review for heatwave hazard events in the Victoria and broader south-eastern Australia context, and (iii) consultations with stakeholder representatives.

Step 2: Identify the economic flows that are exposed to potential heatwave hazard events
Step 2 established the economic flows (goods and services) that are exposed to potential heatwave events and their distribution across geographical areas - measured in terms of 'value add'[8]. These are the 'elements at risk' considered in the analysis. More information on how value add data was generated is outlined in section 3.3 below.

Step 2 also overlayed this 'value add' data with heatwave intensity climate data (measured in terms of EHF index) for three categories of heatwave events. More information on the heatwave events modelled and how the EHF index was calculated for each geographical area are outlined in in section 3.2 and Appendix A.

Note, detailed information on the capital stock of physical assets and the economic value of these assets were not able to be obtained for each sector. For this reason, quantification of damages was not possible in the analysis - as is typically done under the DaLA method. Nonetheless, estimation of impacts on value add is considered sufficient for the purposes/objectives of this study and will capture the bulk of the impacts.

[8] Value add is the measure of economic value of goods and services produced in an area or sector of the economy. In national accounts value add is output minus intermediate consumption. Value add is used to measure gross domestic/state/regional product (GDP/GSP/GRP) (ABS 2012).

Step 3: Assess the sensitivity of economic flows to loss from potential heatwave events
Step 3 estimated the sensitivity of the sector goods/services to loss from potential heatwave events. To this end, basic sensitivity functions (or basic stage-loss curves) were developed to approximate the relationship between heatwave hazard intensity (in terms of EHF) and the extent of losses (in terms of value add) for each sub-sector.

Sensitivity functions were developed through three key sub-steps: (i) a desktop review of available literature and studies to understand the functional form of the relationship between heatwave hazard intensity and extent of losses; (ii) translation of observed impacts from recent heatwave events into approximation of losses (in terms of value add); and (iii) advice and review by sectoral experts (including University academics).

More information on the actual sensitivity functions developed for each sector and sub-sector, and the specific information inputting to these functions, is outlined in the relevant sector chapters.

Step 4: Quantify the impacts on economic flows that can be expected from heatwave events (sector and regional partnership boundary areas)
Step 4 quantified the impacts (in terms of loss of value add) expected from each of the three different heatwave events for each sub-sector across each geographical area.

This was done by inputting the geographically referenced EHF data generated for each heatwave event (part of step 2) into the sensitivity function(s) developed for each sub-sector in Step 3.

Outputs from this calculation (i.e. % change in annual value add) were then applied to corresponding value add data collated in step 2 (i.e. geographically referenced value add for each sub-sector) to provide an estimate of loss.

Step 5: Investigate barriers that are constraining sectors/stakeholders capacity to adapt to/manage heatwave risks
The fifth step examined the barriers and impediments that are considered to be constraining the capacity of households, businesses and (private sector) organisations to autonomously adapt to changing heat wave events in each sector – a key determinant of vulnerability.

This was done as a brief desktop review. Broadly consistent with the Productivity Commission (2012) approach, barriers were categorised into (i) market failures; (ii) policy and regulatory barriers; (ii) governance and institutional barriers; and (iii) equity and distributional barriers.

In addition, following the stepwise procedure for the sectoral analysis, a final summative step was also undertaken to aggregate sector results into macroeconomic effects. To this end sector losses were added together and expressed as a total $ impact as well as % of Gross State Product (GSP) and % of Gross Regional Product (GRP). This was undertaken to give some perspective on the relative importance of heatwave impacts for the overall economy.

Sector coverage
The sectors that were assessed are outlined in Table 1 below. These are the ones identified in literature research to face the greatest heatwave risks, and/or considered to materially contribute to risks experienced in other sectors. Together, they are considered to explain the majority of the overall impacts on the Victorian economy.[9]

Sectors were also selected to be broadly consistent with the scope of the previous vulnerability assessments undertaken on bushfire and flood.

[9] Consistent with 'pareto principle' or '80/20 rule' which states that, for many events, roughly 80% of the effects come from 20% of the causes.

Table 1. Sectors within scope of this assessment

Infrastructure sectors	Productive sectors	Social sectors	Cross-cutting sectors
Electricity	Agriculture	Health	Environment
Transport (rail & road)	Construction		
Water	Manufacturing		
	Mining		
	Tourism		

3.2 Climate modelling adopted

Previous extreme heat studies within Australia and globally have used a variety of methods to estimate the changes to heatwave and extreme heat hazards. The key difference between the methods is whether duration (i.e. number of days of extreme heat) and overnight minimum temperature are taken into consideration. Previous research has highlighted the importance of incorporating a combination of duration and maximum and minimum temperature through the utilisation of daily mean temperature to quantify heatwave intensity (Nairn and Fawcett 2013). Over recent years the CSIRO and BoM have developed the *Excess Heat Factor* (EHF) to provide a suitable heatwave definition that can be used for real time forecasting and assessing future climate change impact.

Excess Heat Factor is defined as the combined effect of excess heat (significance of the event) and heat stress (acclimatisation ability) and expressed as:

$EHF = EHI_{sig} \times max(1, EHI_{accl})$ Equation 1

The first index is a measure of the significance by determining how extreme the temperature conditions are by comparing the 3-day average temperature (mean of daily maximum and daily minimum expressed as: $T = (T_{max} + T_{min})/2$) with the 95th percentile of the daily mean temperature calculated over the period of reference (1971-2000) and is denoted by T_{95}. The 95th percentile at each location is calculated over the entire period; therefore generally all heatwaves identified will occur during the warmer months from November to March:

$EHI_{sig} = (T_i + T_{i-1} + T_{i-2})/3 - T_{95}$ Equation 2

The second index is a measure of acclimatisation and compares the 3-day average temperature with the previous 30-day temperature:

$EHI_{accl} = (T_i + T_{i-1} + T_{i-2})/3 - (T_{i-3} + \ldots + T_{i-32})/30$ Equation 3

A heatwave is identified when EHF is positive and becomes severe when both the EHI_{sig} and EHI_{accl} are positive due to the three day period being above the 95th percentile for daily mean temperature as well as substantially warmer than the preceding 30 days.

The benefits of using EHF to help quantify the impact of heatwaves on the Victorian economy for the current project include:

- The index is a continuum and captures low-intensity heatwaves through to extreme heatwaves and allows for comparison between regions (important for whole of Victorian assessment).
- Used by BoM to forecast heatwaves, therefore consistent with warnings already utilised (e.g. January 2018 heatwave warnings across Victoria).

The key datasets required to calculate EHF across Victoria for historical and future climate periods are daily maximum and minimum temperature. Currently, daily temperature projection data relative to 1986-2005 is only available as time series at 11 high quality BoM stations across Victoria (Figure 3). Gridded model output data is currently only available at an annual, seasonal and monthly temporal scale so is unable to be used to calculate EHF.

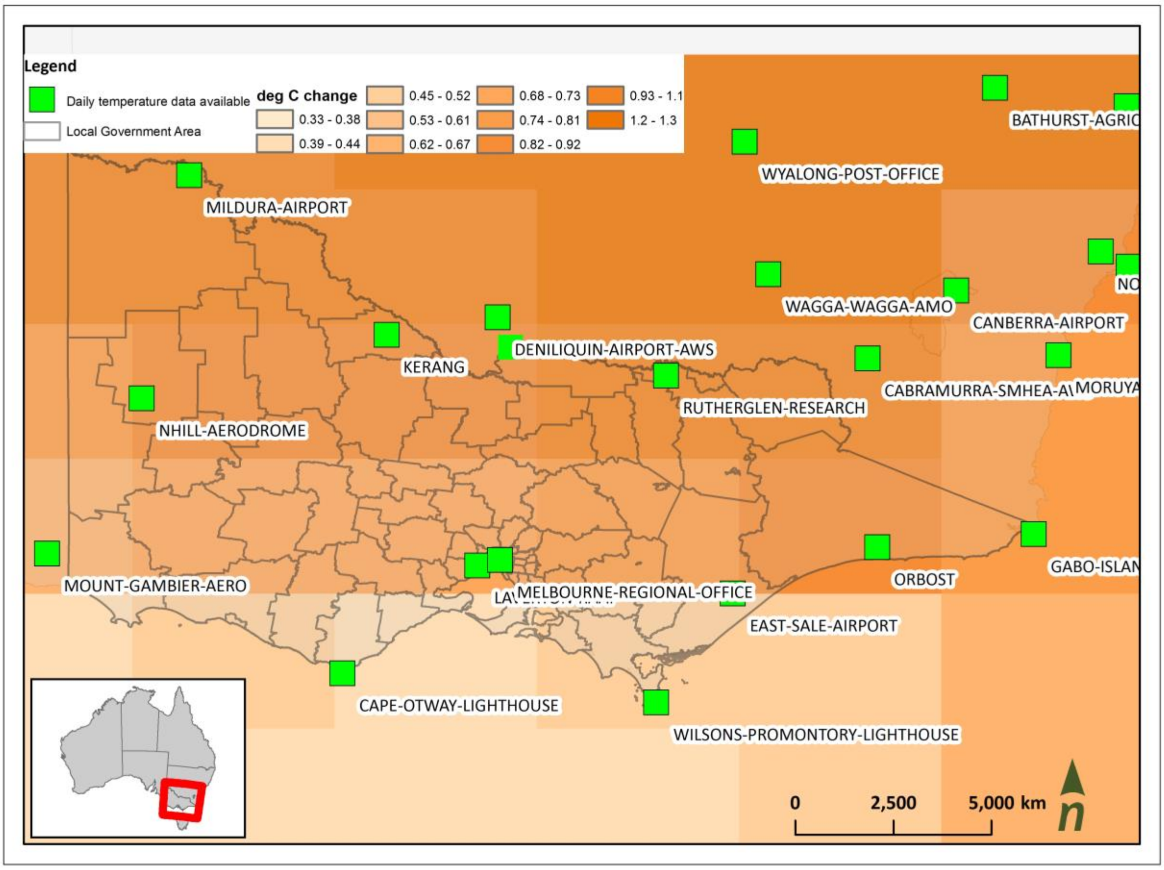

Figure 3 Location of "application ready" daily time series data for climate change projections (emission scenario and time periods)

Three different intensity heatwave events were selected to model the impacts of heatwave hazards on the Victorian economy – in line with the categorisations defined by CSIRO and BoM. These were:

- A 'severe' heatwave event which was defined as the 85th percentile of positive EHF in the historical observed record consistent with CSIRO and BoM severity threshold (Nairn and Fawcett 2013). This event was estimated to have a current (Victorian average) return period of once every 2 years.

- An 'extreme' heatwave which was defined as 3 times the severe threshold consistent with CSIRO and BoM severity threshold (Nairn and Fawcett 2013). This event was estimated to have a current (Victorian average) return period of once every 25 years and are usually associated with widespread adverse impacts.

- An 'very extreme' heatwave which was defined for the purposes of this analysis as a 10% increase on the maximum EHF recorded at each station. This is similar to a hypothetical event developed to inform Victoria's Preparedness Framework - which is approximately a 10% increase on the January 2014 peak in Melbourne (maximum on record). Across Victoria, the maximum historical EHF recorded generally corresponded with either the January 2009 or January 2014 events. An event of this magnitude does not exist in the observed temperature record, however for the purposes of this assessment we have assumed a return period of once every 110 years. This scenario is referred to as the very extreme scenario throughout the report. Note, unlike 'severe' and 'extreme', 'very extreme' does not correspond with any formal categorisation/definition as specified by CSIRO or BoM.

Peak EHF was calculated for each regional partnership boundary area for each of the heatwave intensity events under consideration (i.e. severe, extreme, and very extreme). A map of the regional partnership boundary areas is provided at Appendix B.

Estimation of how the likelihood of each of the heatwave events (i.e. severe, extreme and very extreme) is expected to change in the future under the effects of climate change was modelled using the ACCESS 1.0 model. ACCESS 1.0 was found to perform the best out of the 40 CMIP5 (Coupled Model Intercomparison Project 5) for the Australian climate to characterise future climate change across Victoria. For Southern Australia, the ACCESS 1.0 model is within the 10-90th percentile model variability and is ranked the best model for capturing diurnal temperature range across Australia which is an important indicator for models' ability to represent extreme cold and warm temperature. The model was also ranked the highest for representing Australian historical mean annual surface temperature (CSIRO and BoM 2015).[10]

Future likelihoods (of these three heatwave intensity level events) were calculated for two future time periods – a 2030 (medium term) and 2050 (long term) – and utilising two different greenhouse gas emission[11] scenarios (i.e. RCP 4.5 and RCP 8.5). Datasets used in this part of the climate analysis were taken from the Climate Change in Australia website: Station Data Download Tool.

The results of the future climate analysis are summarised in Table 2 below.

Table 2 Likelihoods of heatwave events under different climate futures

Heatwave event	Likelihood (estimated return period, number of years)			
	Current	2030 (RCP 8.5)	2050 (RCP 4.5)	2050 (RCP 8.5)
Severe	2	1	0.9	0.8
Extreme	25	12.8	11.7	8.7
Very extreme	110	41.3	41.8	25.4

More information on the climate analysis methodology is provided at Appendix A.

3.3 Economic value add data

The key economic data used in the analysis to understand exposure is 'value add'. Value add is a measure of economic value of goods and services produced in an area or sector of the economy[12] (ABS 2012).

The Australian System of National Accounts (ASNA) does not currently maintain accounts for value add data at a regional partnership or sectoral level. As such, this data was required to be 'generated' for this analysis using a the (more aggregated) ABS state account and employment datasets.

The method followed for generating this data was:

Direct sectoral contributions to the Victorian state were estimated using the value added by business activities from the different sectors. A measure of returns to labour and capital was used. The required data was sourced from the Australian Bureau of Statistics' census (ABS 2017b) and Australian national accounts (ABS

[10] While it is preferable to conduct risk assessments using results from multiple climate models, due to the range of economic sectors investigated this was not practical for this project. As each of the economic sectors in Victoria have different thresholds for exposure to extreme heat (i.e. different significance and duration thresholds), to manage the number of modelling runs, we decided to use ACCESS 1.0 only. Further, given the greater uncertainty in the economic data, it was determined the available project resources were best allocated to collecting economic data than additional climate model runs.
[11] or representative concentration pathways
[12] In national accounts value add is output minus intermediate consumption.

2017a). The ABS national accounts report state level employee labour costs and payment to capital for different sectors.

Industry of employment is reported by 'place of usual residence' and by 'place of work'. Since the objective of this study is to estimate the impact of heatwaves on the economy, we adopted the 'place of work' data to better reflect where the physical/economic impact occurs rather than where the people employed live. The exception was the health sector which used 'place of usual residence'. ABS's SA2 aggregation was used as a spatial resolution for employment data.

Equations 1 and 2 provide the general logic used in estimating value added by different sub-sectors at an SA2 aggregation level.

$$Factor\ costs = labour\ costs + payment\ to\ capital \qquad \text{Equation 1}$$

$$Value\ added_{ij} = \frac{GSP\ contribution_i}{Factor\ cost_i} * no.\ of\ employees_{ij} \qquad \text{Equation 2}$$

Where: *I* = sector or sub-sector and *j* = region (SA2)

The SA2 economic impacts were further aggregated at the Victorian regional partnership area level. Appendix B provides more information on boundaries of the regional partnership areas.[13]

Note also, there is no dedicated data for the tourism sector. According to Tourism Research Australia (TRA 2017), tourism accounts for an estimated 14% of earnings (and jobs) from accommodation services and 17% of earnings (and jobs) from the retail sectors. Thus, a proportion of the jobs in accommodation and retail services was used to estimate value add for the tourism sector.

3.4 A note on data and the implications on our estimates

This project is based on the readily available data relating to climate, impacts and economic variables. It should be noted that this data is extremely limited in most cases, necessitating the use of assumptions and surrogate measures to underpin much of the quantitative assessments presented throughout this report. Therefore, the quantitative estimates presented throughout this report should be considered indicative only, as a means to understand the broad materiality and relative distribution of economic vulnerability to heatwave events.

As Victoria's approach to climate change adaptation matures, and modelling and monitoring improves, the quality of data available as inputs to vulnerability assessments will improve, and more confidence in quantitative estimates will be warranted.

In addition, data availability has also limited the scope of the quantitative assessments. Therefore, the estimates presented in this report will generally be underestimates of overall economic vulnerability.

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[13] While most SA2 regions wholly fit into the regional partnership boundaries, there were instance where an SA2 lay across multiple boundaries. In such an instance, the SA2 was assigned to the regional partnership where its larger area was located.

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Part B – Aggregate estimates

4 Aggregate impacts, whole of Victoria

This chapter aggregates (i.e. sums up) impacts for each of the sectors analysed. The main purpose of this is to provide insight on the relative importance of vulnerability (to impacts) across the sectors as well as the importance of heatwave vulnerability for the broader Victorian economy.

Whilst slightly outside scope, this chapter also includes a short examination of the overall level of risk for each of the heatwave events modelled (severe, extreme, very extreme). This helps to give some further perspective on the aggregate impact results reported here.

4.1 Aggregate impacts for each heatwave event category

The total impact from a 'severe', 'extreme', and 'very extreme' level heatwave events are estimated to be in the order of $131 million (0.04% of GSP), $291 million (0.09% of GSP), and $1,000 million (0.31% of GSP) respectively. The relative sectoral contribution to each of these aggregate impacts is illustrated in Figure 4 below.

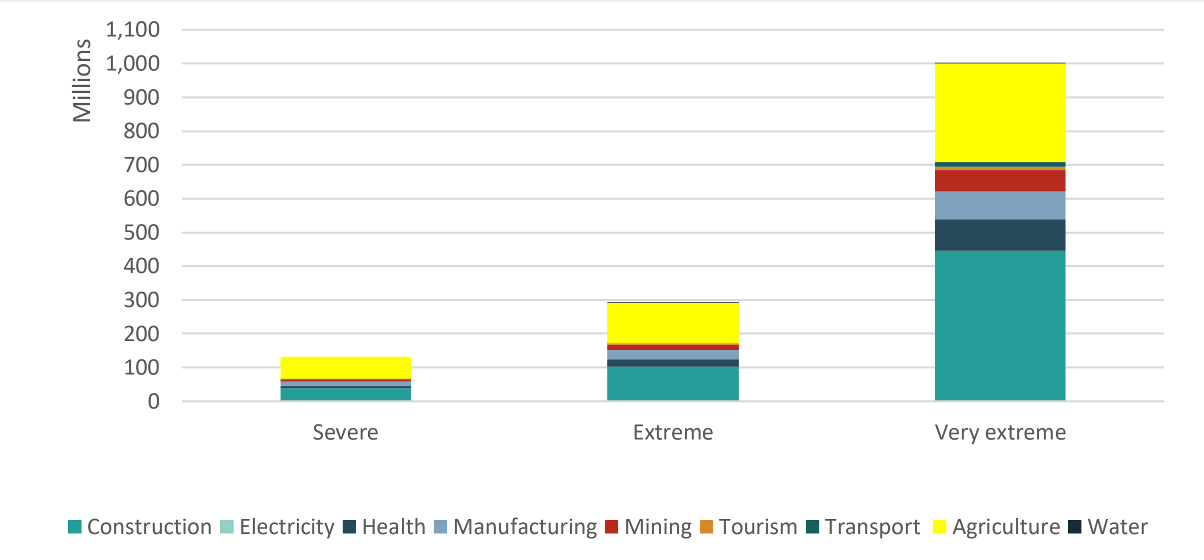

Figure 4 Aggregate impacts for each heatwave event modelled, disaggregated by sector

As can be seen, for severe level heatwave events almost half of total impacts are from the agriculture sector. Construction is also a major contributor, making up around one quarter of total impacts. Manufacturing, health, and mining are important too - together making up almost a quarter of impacts.

Sectors that contribute little to total impacts are tourism and the infrastructure sectors - electricity, transport, and water. It should be noted here that impacts to the environment sector - along with its contribution to other sectors - were not quantitatively assessed but are expected to be relatively large/important. This is discussed further in Part C of this report.

For 'extreme' and 'very extreme' intensity heatwave events, the proportionate share of impacts from manufacturing, health, mining, tourism, electricity, transport, and water remain approximately the same. The key differences pertain to the agriculture and construction sectors. Agriculture and construction both make up approximately a third of total impacts each for extreme level events. For very extreme level events, the construction sector makes up almost half of total impacts and agriculture around one quarter.

A key thing to note is that electricity sector vulnerability may substantially increase in the future - as existing coal-powered generators reach the end of their useful life and are retired; and if barriers constraining efficient functioning and adaptive capacity of the (rapidly evolving) NEM are not addressed.[14] As such, the above results for current vulnerability are not a reliable indicator of future vulnerability in the electricity sectors' case.

4.2 Risk for each heatwave event category

To get a better sense of the importance of the above-reported impacts/vulnerability[15] it is helpful to consider these impacts alongside the likelihood of the given (intensity) events occurring. This gives a picture of the overall level of (heatwave) risk at play.

Table 3 summarises annual 'expected' impact, or risk, from each of heatwave category levels and how this is calculated. Figure 5 also illustrates these same results in graphical form, further breaking it down into its sector contributions.

Table 3 Annual 'expected' impact from each of heatwave category levels

Heatwave intensity	Likelihood for current period, Victoria average (return period) [A]	Absolute Aggregate impact ($Millions) [B]	Annual 'expected' impact ($Millions) [A x B]
'Severe'	Once every 2 years	131	66
'Extreme'	Once every 25 years	291	12
'Very extreme'	Once every 110 years	1,000	9

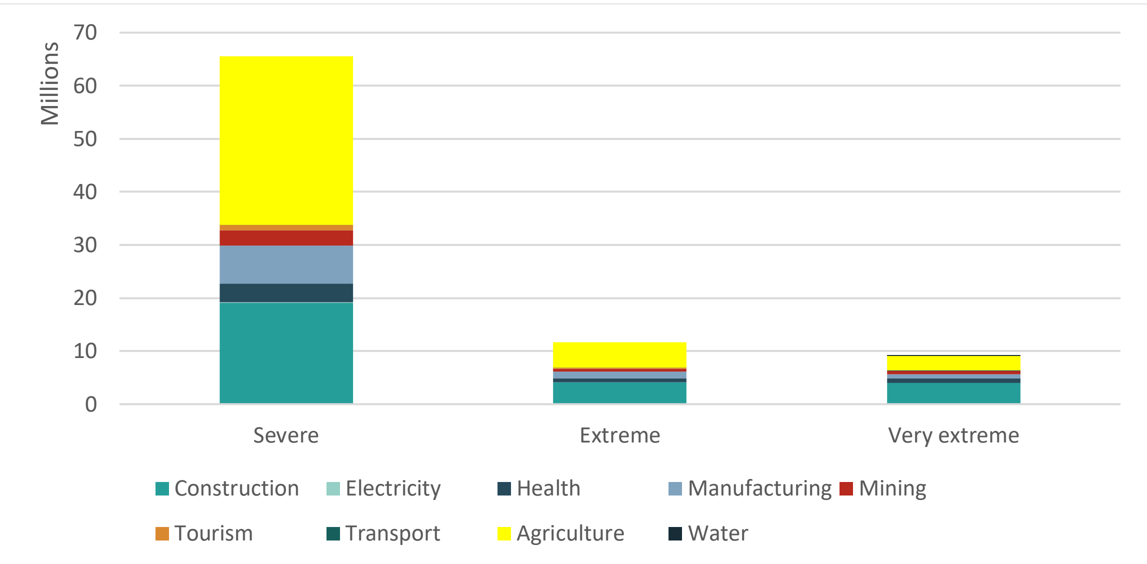

Figure 5 Annual 'expected' impacts for each heatwave event modelled, disaggregated by sector

A key insight from these results is that, even when likelihoods are factored in, the 'expected' impact from heatwave events is substantial. Every year, on average, the loss from heatwave events is in the order of 0.025 per cent of GSP – based on current climate and economic conditions.

[14] These impacts could manifest as service disruptions or as substantially higher costs of service delivery (i.e. higher electricity prices).
[15] As a policy issue.

Another key insight from these results is that severe events, whilst lower in absolute terms compared to extreme and very extreme level events, currently presents the greatest risks to the Victorian economy because they happen much more often. The annual expected impact from this level event is substantial, estimated to be in the order of $66 million per annum. At this point in time, these events – and the sectors most vulnerable (especially agriculture) to them - are of most concern for the Victorian economy.

When climate change is taken into account, the situation changes somewhat into the medium (2030) and longer term (2050) future as the likelihoods of each of these events increase.[16] Table 4 summarises annual expected impact from each of heatwave category levels in future time periods - assuming vulnerabilities remain at their current levels.

Table 4. Annual 'expected' impact from each of heatwave category levels for future periods

Heatwave intensity	2018 Annual 'expected' impact ($Millions)	2030 (RCP 8.5) Annual 'expected' impact ($Millions)	2050 (RCP 4.5) Annual 'expected' impact ($Millions)	2050 (RCP 8.5) Annual 'expected' impact ($Millions)
'Severe'	66	132	146	174
'Extreme'	12	23	25	33
'Very extreme'	9	24	24	39

A key insight from these latter results is that – if nothing is done to reduce vulnerabilities – overall heatwave risk substantially increases in the future under the effects of climate change.

Also, higher level heatwave intensity levels modelled – i.e. extreme and very extreme – proportionately increase relative to severe level events. All category events – and sectors that are vulnerable to each of these level events – are thus of concern for the Victorian economy and will be important to manage.

[16] the likelihood values used (in the expected value calculations) for each of the assessed heatwave events (i.e. 'severe', 'extreme', and 'very extreme') in future time periods are outlined in Section 3.2 above.

5 Aggregate impacts, distribution across geographical areas

This chapter shows how aggregate impacts are distributed across geographical areas. The main purpose of this is to provide further insight on the relative importance of vulnerability (to impacts) across regions. Figure 6 below shows annual expected impacts across regional partnership areas. As can be seen the region that is most affected in absolute terms is Melbourne – by far. This reflects the fact that most of Victoria's population and economic activity occurs in this area.

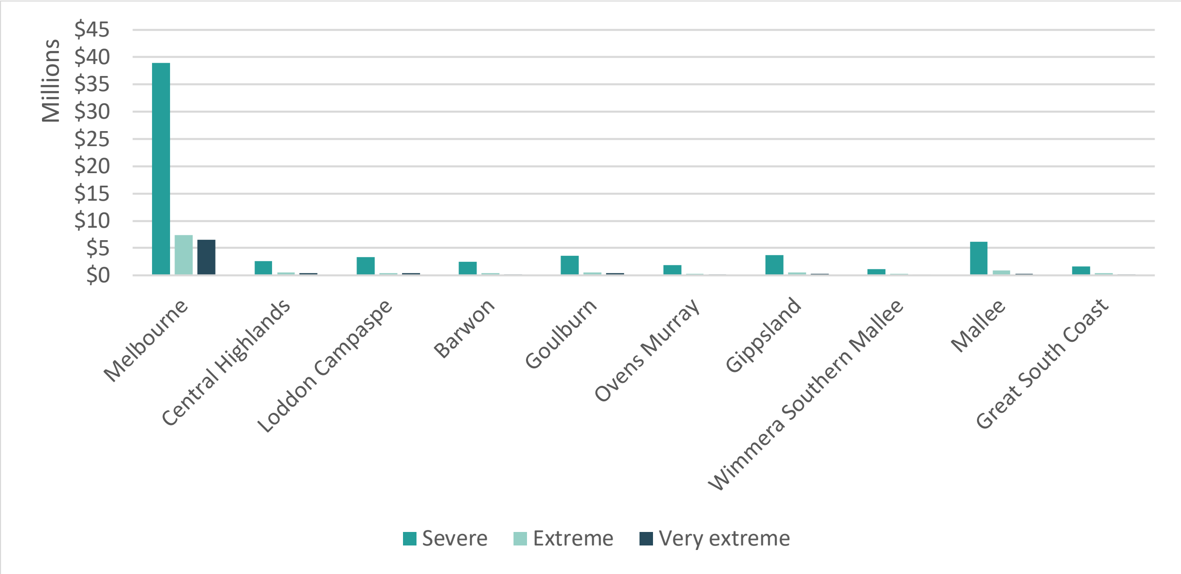

Figure 6 Annual expected impact by regional partnership area

Figure 7 shows the distribution of impacts as a percentage of Gross Regional Product (GRP). In contrast to absolute impacts, these results show the Mallee, Wimmera/Southern Mallee, and Goulburn areas as the most proportionately affected by heatwaves. These regional economies have a high dependency on the agriculture sector. Melbourne is proportionately much less affected and is in fact the lowest out of all regions in the State. This reflects a more diversified and less agriculture-intensive economy for that (mostly metropolitan) region.

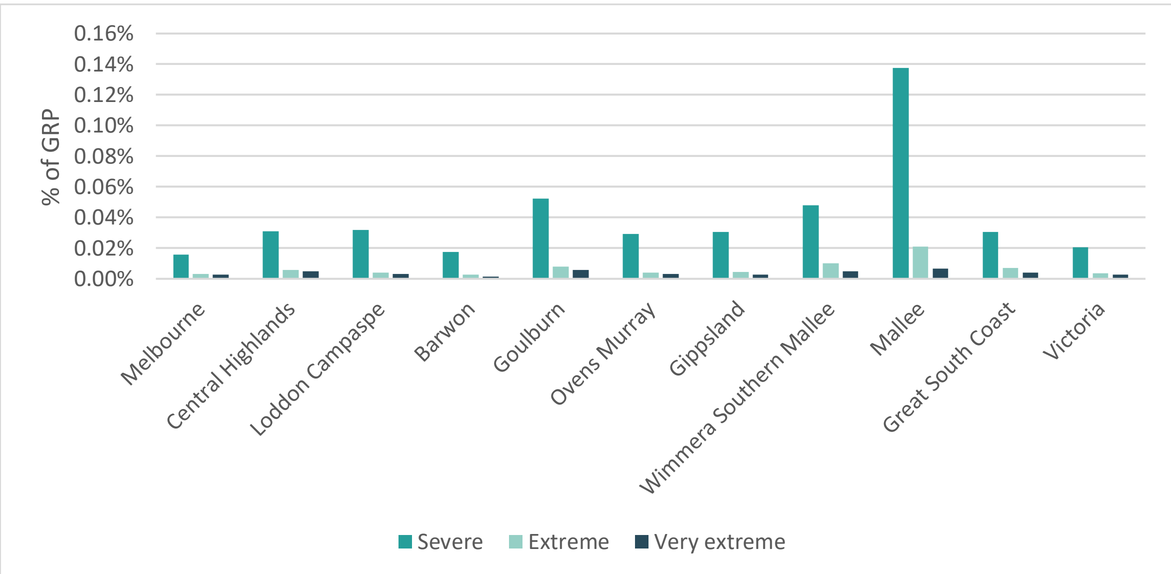

Figure 7 Annual expected impacts as a % of Gross Regional Product (GRP)

Part C – Sector Assessments

Part C of this report summarises the assessments undertaken for each of the sectors. 'Infrastructure' sectors are discussed first, followed by the 'productive' sectors, and then the health sector (social sector). The 'cross-cutting' environment sector is also discussed at the end.

For each sector, the assessment is organised as follows:

- Context.
- Nature of Impacts. This section explains the types of damages and losses experienced from heatwave events, and the causal links for these effects.
- Sensitivity to Impacts. This section describes the sensitivity – or degree of impacts – expected from heatwave events. This includes a brief explanation on how the 'sensitivity functions' have been developed and a graphical illustration of these functions.[17]
- Extent of Impacts. This section reports the quantitative estimates of impacts[18] for each of the heatwave events modelled – 'severe', 'extreme', and 'very extreme'.
- Probability-weighted extent of impacts and climate change. This section reports the 'annual expected' impacts taking into account the likelihood of each level heatwave event occurring in a given year. This is done for the current period (2018) as well as for 2030 and 2050[19]. Among other things, this is intended to provide insight on the implications of climate change.
- Distribution of Impacts across Geographical Areas. This section reports how estimated impacts are distributed across regional partnership boundary areas.
- Barriers to effective adaptation. This section briefly identifies some of the key barriers that are affecting the sectors' capacity to adapt to the effects of changing heatwave events.
- Concluding Remarks.

[17] Amongst other things, this is intended to help further explain to interested readers how impact estimates have been derived.
[18] Recall from methodology, this is calculated by combining exposure (value add overlayed with EHF) with sensitivity.
[19] utilising heatwave event likelihood information outlined in section 3.2 (climate modelling)

6 Electricity

6.1 Context

The Victorian electricity system is part of a broader national inter-connected electricity system that spans the eastern and southern states of Australia - including Queensland, New South Wales (including Australian Capital Territory), Victoria, South Australia, and Tasmania.

This national electricity system – known as the *National Electricity Market (NEM)* - is made up of several discrete components. These include generation (production of electricity from source energy), transmission (transport electricity across long distances at high voltage), distribution (transport electricity within localised grids at lower voltage), the retail companies (responsible for purchasing wholesale electricity and on-selling to most end users), and end users (households, small-scale businesses, large-scale businesses etc). Increasingly, small-scale alternative energy providers (e.g. household solar panels and batteries) are also integrating into this system. Figure 8 illustrates this electricity supply system.

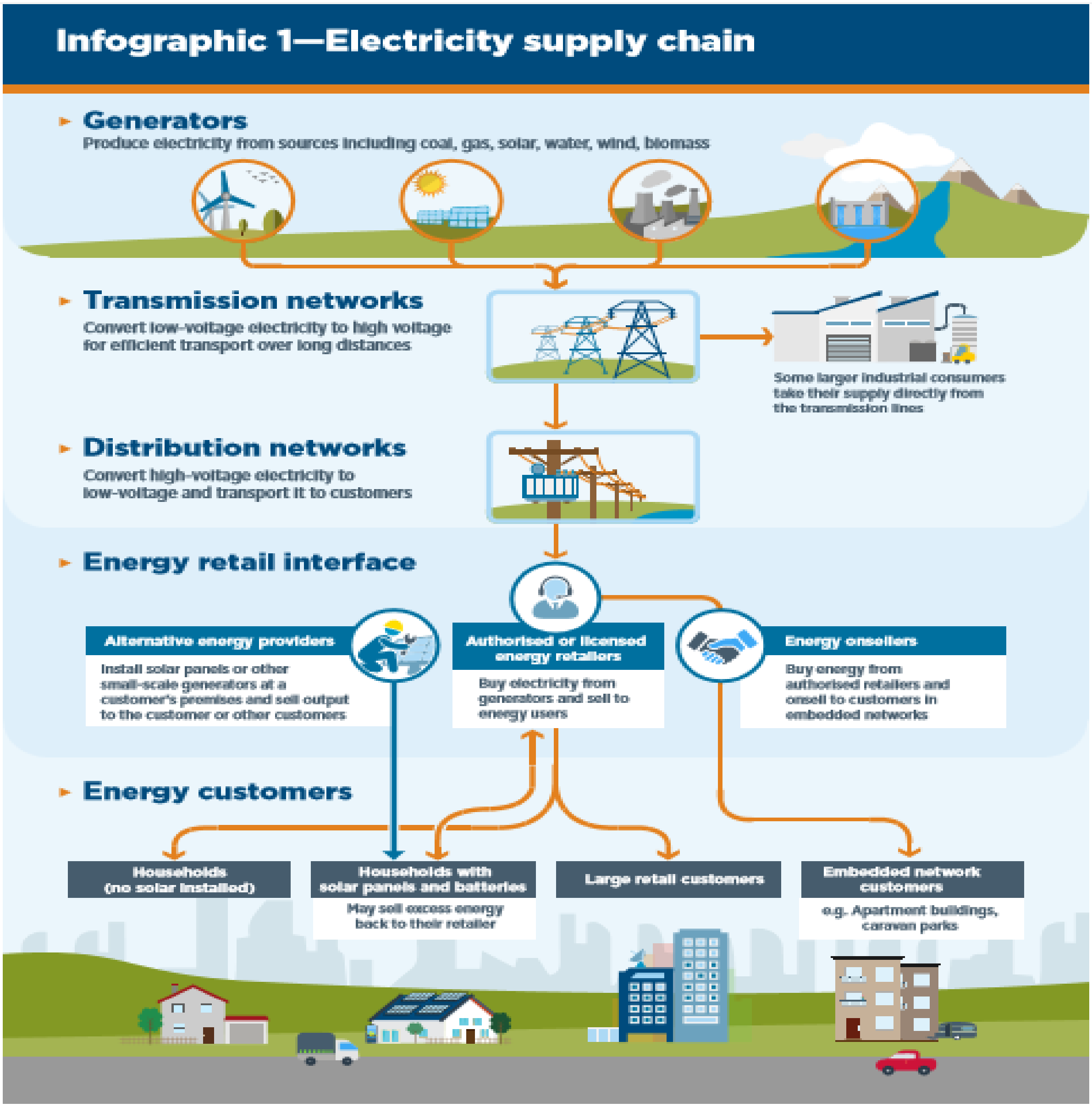

Figure 8 National electricity supply system (AER 2017)

Electricity infrastructure across the NEM comprises both state and private assets managed by industry participants (AEMO 2018a). In Victoria, private entities own most generation capacity[20] (AER 2017) as well as natural monopoly transmission and distribution infrastructure.[21]

The electricity system is in the midst of a transformation driven by technological change (AEMO 2018b). Distributed energy resources[22] (DER) and wind and solar energy technologies have substantially decreased in cost in recent years, spurring 'decentralization' of generation. Similarly, digitalization of both the grid[23] and DER are creating new market participants and changing how customers engage with the system (WEF 2017).[24]

6.2 Nature of expected impacts

Heatwaves can impact on the national electricity market in a range of different ways. Key impacts are felt by the generation, transmission, distribution, and end-user-demand components of the systems - which in turn can result in (intentional or unintentional) blackouts[25] and brownouts[26] (i.e. electricity service disruptions).

For generation, high ambient temperatures directly affect the efficiency of generator operation (Aivalioti 2015) and can lead to breakdowns (Finkel 2017). This applies to fossil fuel, nuclear, solar photovoltaic, and wind types of generation (AEMO 2018b). When electricity output from a generation unit in Victoria is compromised (from direct heat impacts), this shortfall can potentially be made up by additional supply provided from a different generation unit within the NEM – including units located interstate.

For transmission and distribution components of the electricity system, heatwaves directly affect the efficiency of operation, and can also lead to breakdowns. High ambient temperatures limit the conductivity of cables and affect functioning of power and instrument transformers[27] (QUT 2010). Many elements of the transmission and distribution systems also have maximum operating temperatures above which they disconnect to avoid damage (Finkel 2017).[28]

Heatwave conditions further affect the electricity system through spikes in electricity demand – referred to as 'peak demand'. Households are a major driver of peak demand during heatwave events through increased usage of air-conditioning.[29] If there is not sufficient back-up generation capacity across the broader NEM system, or is not accurately forecasted and actioned as needed, peak demand can result in a supply shortfall (supply demand imbalance) and associated service disruptions during these times. Peak demand also creates higher "loads" for transmission and distribution networks. If higher loads go above technical design limits of this infrastructure[30], then the system is required to 'shed' load to avoid broader service disruptions.[31] To address these matters, some major industrial electricity customers are now contracted to 'load shed' during peak demand periods as part of their service agreements - including appropriate commercial compensation.

Peak demand is a major determinant of electricity prices, which has markedly increased in recent years.

[20] AGL Energy (31 per cent), Energy Australia (25 per cent) and Snowy Hydro (22 per cent)[20] (AER 2017).

[21] Victoria has a unique transmission network structure, which separates asset ownership from planning and investment decision making. SP AusNet owns the state's transmission assets, but the Australian Energy Market Operator (AEMO) plans and directs network augmentation. AEMO also buys bulk network services from SP AusNet for sale to customers.

[22] Distributed energy resources (DER) refers to often smaller generation units that are located on the consumer's side of the meter.

[23] with smart metering, smart sensors, automation and other digital network technologies.

[24] Also, developments in electric vehicle (EV) technologies are expected to further shape the electricity supply system into the medium-term future (WEF 2017).

[25] A blackout is defined as a complete power loss affecting many electric users over a large area for an extended period. Residents and businesses lose power and the entire area temporarily goes black (Battaglia 2014).

[26] A brownout is defined as a controlled power reduction or loss of electricity to pockets of customers. A brownout is caused by a state of "poor power quality" in which a utility may reduce line voltage to deliver more electricity to meet increased demand (Battaglia 2014).

[27] Transformers are electromagnetic devices that change the voltage or current of electrical energy.

[28] In addition, transmission lines can expand with hot weather, causing the cable to sag below height limitations and potentially becoming an ignition source for bushfires.

[29] Indeed, households make up around two-thirds of total electricity demand during peak demand periods compared to around one quarter normally (Chester 2012). Moreover, the building sector is a major electricity consumer globally and accounts for half of all electricity consumed (Aivalioti 2015).

[30] Transmission and network infrastructure capacity cannot quickly increase to accommodate loads due to technical (design limits).

[31] It is further noted that, increasing design load limits for transmission and distribution infrastructure is very, very costly and has been a major driver of electricity price increases in recent times.

The nature of heatwave impacts for the electricity sector is summarised in Table 5 below.

Table 5. Types of damages and losses expected in the electricity sector

Damages	Losses
Damage to, and reduced operational efficiency of, generation infrastructure	Electricity service disruptions
Damage to, and reduced operational efficiency of, transmission and distribution infrastructure (direct ambient temperature + increased "load" associated with peak demand)	

This quantitative analysis will assess losses to the electricity sector pertaining to heatwave-related service disruptions[32]. Knock-on effects from electricity service disruptions on other sectors are (partially) analysed in those sector chapters.

The effects of peak demand and related interventions to maintain system security and reliability on electricity prices are not quantitatively assessed.

In early 2009, Victoria suffered through a long and intense heatwave event that took a significant toll on the electricity sector. In Melbourne, the EHF index peaked at 122 with temperatures reaching over 43 degrees for three consecutive days.

During this event, electricity demand driven primarily by air conditioning broke previous records for Victoria by approximately 7 per cent. Supply was compromised during this time by a combination of:

- A shutdown of the Basslink transmission connection between Tasmania and Victoria (which, at the time, provided around 6 per cent of Victoria's electricity).
- An inability of NEM generators to supply additional power.
- Faults in instrumentation transformers (in one case, an explosive incident), leading to outages of major transmission lines which restricted the ability to supply load to the Western metropolitan area and beyond.
- Faults in up to 50 local voltage transformers.

As a result, it is estimated that over 500 000 residents in Melbourne were without power for the evening of 30 January 2009. The incident resulted in rolling blackouts throughout western and central Melbourne for times that ranged from an hour to two hours (QUT 2010).

Box 2 Case study example of impact on electricity sector from 2009 heatwave event

6.3 Sensitivity to impacts

The capacity of the NEM to deal with peak-demand effects is the key determinant of the electricity sectors sensitivity to heatwave events at this point in time (AEMO 2017). For the 2017-18 and 2018-19 summers, the Australian Energy Market Operator (AEMO) estimates there is sufficient capacity within the NEM[33] to meet

[32] In terms of unserved energy. Unserved energy (USE) is the amount of energy that cannot be supplied to consumers, resulting in involuntary load shedding (loss of customer supply), because there is insufficient generation capacity, demand side participation, or network capability to meet demand.
[33] This incorporates new Government initiatives to introduce storage batteries and emergency generation.

peak demand for lower intensity heatwave conditions (roughly commensurate with a 1 in 2 year event) without experiencing any material disruptions[34]. For peak demand roughly commensurate with a 1 in 10 year heatwave event, the current NEM capacity is such that only five localised observations of unserved energy[35][36] lasting a few hours each are expected in Victoria - on average.[37,38]

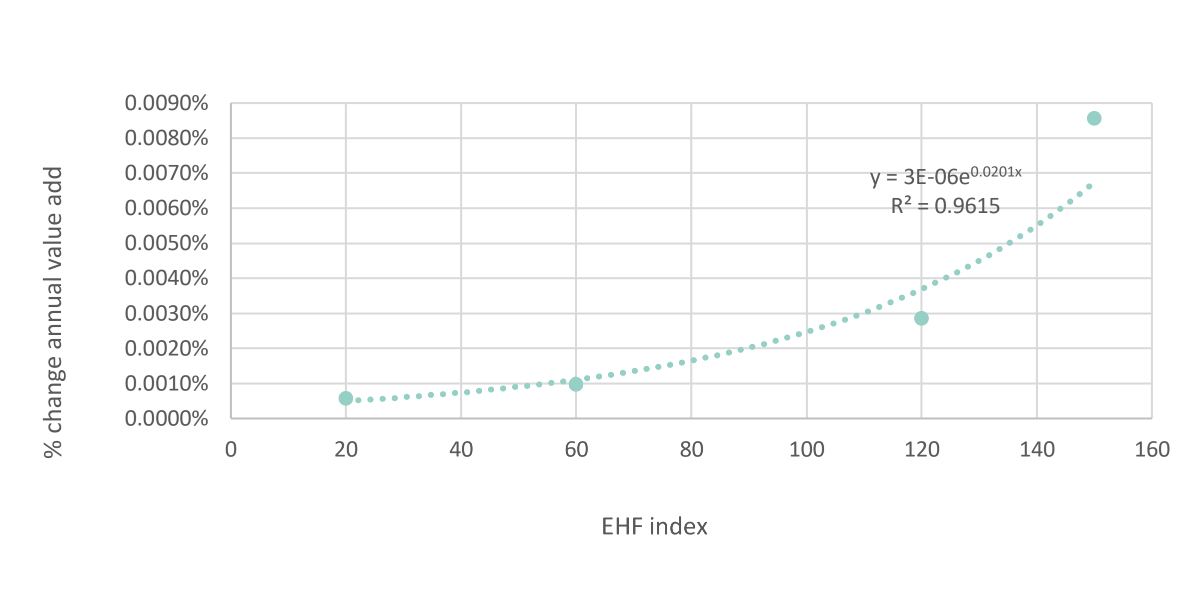

Figure 9 Sensitivity function for electricity sector

The overall sensitivity of the electricity sector to losses (in terms of economic value add) from heatwave events (measured in terms of EHF) is approximated in the 'sensitivity function' at Figure 9 below.[39] This function is based on the electricity supply adequacy risk assessments undertaken by AEMO as part of its Energy Supply Outlook paper (AEMO 2017). It also incorporates:

- Observed impacts for Melbourne for the January 2018 heatwave event.
- Observed impacts for Melbourne for the 2009 heatwave event (QUT 2010).
- A hypothetical heatwave consequences scenario developed to inform Victoria's Preparedness Framework.

Importantly, the capacity of the NEM to deal with peak-demand effects could materially change in the near-term future as older coal-powered generators reach the end of their useful life and are retired. New generation in the NEM is required (AEMO 2017) to replace this capacity however there are a number of

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[34] The AEMO examined a scenario examining peak demand levels expected to occur once every two years (50% probability of exceedance). Results of this modelling indicate that expected levels of unserved energy for Victoria are around 0.0001% - which is within the NEM reliability standard of 0.002%.
[35] Unserved energy (USE) is the amount of energy that cannot be supplied to consumers, resulting in involuntary load shedding (loss of customer supply), because there is insufficient generation capacity, demand side participation, or network capability to meet demand.
[36] The AEMO examined a scenario examining peak demand levels expected to occur once every ten years (10% probability of exceedance). Results of this modelling indicate that less than five localised observations of unserved energy are expected - which is within the NEM reliability standard of 0.002%.
[37] Under these conditions, the Victorian part of the national electricity market is expected to import electricity from other states to meet periods of high demand (that also coincide with low renewable generation). There is thus a high reliance on transmission infrastructure to import electricity from Queensland and New South Wales at these times The NEM grid is long and linear, with much less network "meshing" than many international power systems (Finkel 2017, p.53).
[38] Detailed modelling has not been performed by AEMO - or is not publicly available - for peak demand commensurate with a 1 in 25 year event or higher.
[39] The impact on (annual) value-add for the electricity sector is assumed to be the same proportion as the proportion of households that are impacted by a service disruption(s) – and accounting for the length of time that the disruptions lasts (typically 1-2 hours).

barriers constraining private investment – including barriers affecting the integration of new technologies (solar, wind, DER etc). These barriers are discussed further in section 6.7 below.

6.4 Extent of potential impacts

The magnitude of losses for the electricity sector (associated with service disruptions) is estimated to be low for all of the heatwave intensity scenarios examined at this point in time. Even under the high intensity level scenario, the losses for the sector from service disruptions is only in the order of $160,000. See table below for a summary of results.

Table 6. Quantification of loss in the electricity sector (expected annual losses)

Sub-sector	Losses ($Millions)		
	'Severe' heatwave event	'Extreme' heatwave event	'Very extreme' heatwave event
Electricity	0.014	0.038	0.160
Total	0.014	0.038	0.160

It should be highlighted again that impacts on other sectors from electricity service disruptions (in terms of inconvenience, lost production etc) are not captured in the electricity sector component of the national accounting framework. Accordingly, results reported here only reflect part of the economic impacts relating to electricity service disruptions.

Furthermore, as highlighted above, vulnerability of the electricity sector may substantially increase in the medium-term future if the barriers currently constraining the capacity of the market to function efficiently and adapt to heatwave hazards are not addressed. Key barriers are discussed in the section 6.7 below.

6.5 Probability-weighted extent of impacts

The probability-weighted magnitude of losses for the electricity sector is summarised in Table 7. This table also includes impacts for future time periods (2030 and 2050) - assuming vulnerabilities remain at their current levels[40].

Table 7 Annual expected impact for electricity sector for each heatwave category

Heatwave intensity	2018 Annual 'expected' impact ($M)	2030 (RCP 8.5) Annual 'expected' impact ($M)	2050 (RCP 4.5) Annual 'expected' impact ($M)	2050 (RCP 8.5) Annual 'expected' impact ($M)
'Severe'	0.01	0.01	0.02	0.02
'Extreme'	0.00	0.00	0.00	0.00
'Very extreme'	0.00	0.00	0.00	0.01

[40] Noting again, vulnerability of the electricity sector may substantially increase in the medium-term future as coal-powered generation plants are retired and if the barriers currently constraining the capacity of the market to function efficiently and adapt to heatwave hazards are not addressed.

For the reasons outlined in sections 6.3 and 6.4 above, caution should be exercised when interpreting the above results. These results only capture part of the heatwave impacts relevant for the electricity sector[41]. Also, they do not account for how sector vulnerability may potentially increase in the future if barriers constraining the (rapidly changing) sectors capacity to function efficiently and adapt to heatwave risk specifically are not effectively addressed.

6.6 Distribution of impacts across regional partnership areas

Figure 10 illustrates the distribution of (very low) impacts across the different Regional Partnerships in Victoria. The results indicate that Melbourne incurs majority of impacts, albeit very minor.

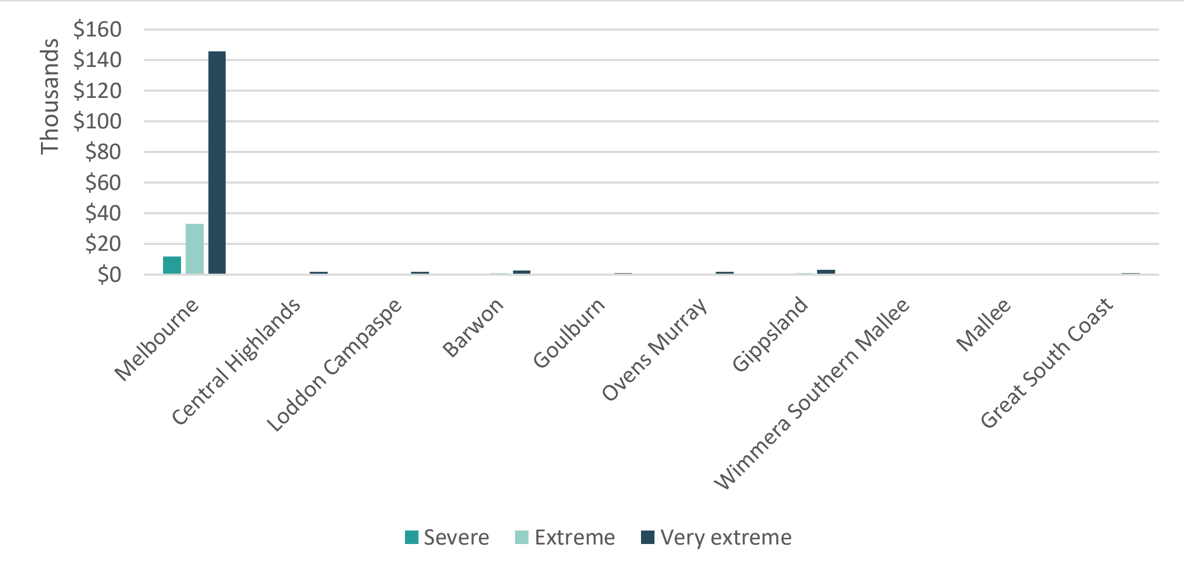

Figure 10 Distribution of electricity losses across regional partnership areas, by heatwave intensity level

6.7 Barriers to effective adaptation

There are a wide range of barriers and impediments that constrain the electricity sectors capacity to function efficiently and adapt to changing heatwave-related risks specifically. These barriers may manifest as higher levels of electricity demand (per household and per unit of production in industry), lower levels/higher costs of electricity supply (security), lower capability to dynamically balance supply and demand, and higher incidences of infrastructure malfunction. This in turn would lead to:

- Reductions in both electricity security and reliability, and ultimately service disruptions during heatwave events; and/or
- The costs of maintaining system security and reliability standards – and in turn further drive up electricity prices.

Substantial policy effort is already being allocated to understand and address many of the barriers and impediments currently constraining the electricity sector. Select barriers that are emphasised in this study are ones which are 'cross-sectoral' in nature and which will thus require increased coordination and collaboration across traditional sectoral policy boundaries to effectively address. These barriers are summarised in Table 8 below.

[41] i.e. service disruptions only (not price impacts) and only as they effect value add of the electricity sector.

Table 8. Barriers constraining capacity of electricity sector to adapt to heatwaves

i. Market failures	
Information failures	There appears to be a lack of reliable and/or a lack of confidence in weather and climate information that is available to NEM participants to input to demand forecasting and climate risk management of infrastructures. For example, the Australian Energy Market Operator's (AEMO) report into the February 2017 power supply shortfalls in South Australia found that there were errors in the temperature forecast information which lead to errors in demand forecasting. This is applicable to Victoria as AEMO is responsible for demand forecasting in Victoria and has access to the same quality climate information for Victoria as is available for South Australia.
	Many households do not have easy access to (real time) information explaining electricity prices, including during peak demand periods. This affects some households' ability to effectively manage electricity consumption during heatwave events. In turn, this may lead to increase usage of electricity during heatwave events (above what it otherwise would be) and thus exacerbates effects associated with peak demand. It also affects households' ability to make informed decisions relating to the installation (and optimal integration of) of batteries, rooftop solar, and other small-scale generation technologies – which can help to reduce reliance/dependence on large-scale generators and transmission/distribution infrastructure in times of heatwave events and, as mentioned above, affects peak demand. Similar problems also exist with respect to the thermal efficiencies of new builds, and the degree to which they reflect future climate parameters.
Split incentives in residential housing	Differing incentives between owners and occupants of residential dwellings can lead to housing stock that is not (optimally) energy/thermally efficient[42] (VCOSS 2017). This may occur when a prospective occupant does not accurately evaluate the owner's choice of energy efficiency of the dwelling, reducing the owner's incentive to properly insulate the dwelling or (where appropriate) install air-conditioning units. Poor energy-efficient housing in turn can increase usage of energy during heatwave events (above what it otherwise would be) and thus exacerbates effects associated with peak demand. The building sector is a major electricity consumer globally and accounts for half of all electricity consumed (Aivalioti 2015).
'External' benefits of distributed energy resources (e.g. rooftop solar photovoltaic and battery storage)	Small-scale alternative energy such as rooftop solar photovoltaic and battery storage generates benefits for households in terms of reduced utility bills and avoided service disruptions. Distributed energy resources, if optimally integrated, can also generate wider benefits to the broader NEM system by helping to improved system security and reliability (Finkel 2017). However, for a number of reasons[43], households are generally not fully rewarded (in financial terms) for their contribution to reducing peak demand (Finkel 2017) and associated system security and reliability.[44] As such, there is a lack of incentives

[42] For older housing stock not subject to new building code regulations.
[43] These include, but are not limited to, inadequate regulation of retail electricity market to serve consumer interests, misaligned incentives for networks (Finkel 2017, p.42-3), and inadequate regulations to 'orchestrate' DER inputs (Finkel 2017, p.62).
[44] Payment received by households for providing electricity into the grid is set at standardised 'feed in tariff' rates. These rates or structures do not account for 'time of use'.

	for individual households/businesses to install distributed energy resources and integrate them into the NEM – at least not to the level that is socially optimal.
'External' benefits of green housing design	Green housing design (e.g. green roofs, vertical gardens) can reduce heat load (from heatwave events) for households as well as for neighbouring households and business areas. As such green housing design is potentially an important adaptation response in urban environments (especially where the 'urban heat island' effect is shown to be material) that could also reduce the need for air-conditioning and associated peak demand effects. However, because some of the benefits of green design - specifically 'spill over' cooling benefits on neighbouring areas - are not fully captured by (private) providers, there is a lack of incentives for individual households/businesses to provide green urban infrastructure - at least not to the level that is socially optimal.
'External' benefits of urban forest ecosystems and other similar green public spaces	Similar to the above, greenspaces such as urban forests and parks can reduce heat load (from heatwave events) for neighbouring households and business areas. As such greenspaces/urban forest ecosystems is potentially an important adaptation response in urban environments (especially where the 'urban heat island' effect is shown to be material) that could also reduce the need for air-conditioning and associated peak demand effects. However, because these cooling benefits of ecosystems 'spill over' to multiple parties, there is a lack of incentives for individual households/businesses to provide or adequately manage greenspaces/urban forest ecosystems - at least not to the level that is socially optimal.
ii. Policy and regulatory barriers	
Uncertain and changing national climate change mitigation policy	Uncertainty about national climate change mitigation policy is affecting investor confidence (AER 2017) and is widely cited as a factor stalling private sector investment in new generation capacity – including efficient reserve capacity to meet peak demand levels during heatwave events. For a sector characterised by very high-cost and long-lived assets, policy transparency, credibility and durability are key (Finkel 2017).
Regulatory barriers to distributed energy resources (small-scale energy technologies) integration and 'orchestration'	Several regulatory barriers constrain the uptake of distributed energy resources (small-scale technologies integrated to the grid) and their efficient integration and 'orchestration' into the grid to support system security during heatwave events (Finkel 2017). As mentioned above, one of the key barriers pertains to the price households receive for feeding electricity back into the grid. These prices are regulated at standardised 'feed-in tariff' rates, which are neither time-sensitive nor include payment for system security benefits (including services relating to frequency control, reactive power, and voltage control). Another key barrier pertains to control mechanisms to 'orchestrate' DER inputs – that is, mechanisms in place to coordinate and optimise DER dispatch into the NEM grid in a dynamic manner.
Barriers to new technologies as an alternative to	Individual power systems and microgrids (separate and standalone to the main electricity grid) using technologies such as solar photovoltaic and storage have the potential to provide more reliable and lower cost alternatives to a traditional

traditional grid connections	connection in the interconnected distribution network – including during heatwave events. Individual power systems and microgrids are not currently regulated under the national frameworks and are subject to separate state and territory legislations. There are gaps in Victoria's (and other states) regulations and that this may be acting as a barrier constraining adoption of these technologies (Finkel 2017).
iii. Governance and institutional arrangements	
Lack of effective integration of energy policy and climate change mitigation policy + lack of strategic national energy planning	In 2016, the Commonwealth Government commissioned an independent review of the future security of the NEM - the 'Finkel Review'. Stakeholders interviewed for that Review identified governance as a key concern, particularly a perceived lack of effective integration between energy policy (primary responsibility of States and Territories through the COAG Energy Council) and emissions reduction policy (primary responsibility of Commonwealth Government). Stakeholders also called for a clear strategic focus for the COAG Energy Council's work. The Finkel Review highlighted that transmission planning is a key barrier constraining the NEMs capacity to deliver secure electricity services into the future – including during peak demand heatwave periods. It identified differing governance arrangements between states for transmission planning, misalignment of incentives between generators and transmission network service providers (in part due to structural reforms), inadequacy of incremental investment decision making criteria used by the AEMO, access pricing arrangements, and a lack of a longer term strategic direction as some of the key component issues.
iv. Disadvantaged groups (equity)	
Public housing	Low income groups are constrained in their capacity to efficiently manage heatwave risks by a lack of available finances. This can contribute to inefficient adaptation strategies, or potentially maladaptation. For example, it may lead to an over-reliance on air-conditioning if they cannot afford energy-efficient housing which in turn will increased peak demand. One dimension of social disadvantage that warrants special attention for heatwaves is housing, and public housing specifically. The majority of Australia's existing housing stock is 20 years of age or older and most of this stock has been built with little consideration of intense heatwave events and climate change (Barnet et al 2013). Disadvantaged populations are more likely to reside in this older, less heatwave-resilient housing stock, and have fewer resources to invest in related adaptation (Barnet et al 2013).

6.8 Concluding remarks

The vulnerability of the electricity sector to heatwave events – in terms of electricity service disruptions - is considered low at present. However, this may change in the near-term future, particularly as older coal-powered generators reach the end of their useful life and the system transitions to new and very different technologies.

There are very material barriers constraining the capacity of the electricity market to function efficiently and to adapt to heatwave risks specifically. These barriers, if not effectively addressed, may:

- Significantly increase the electricity sectors vulnerability (to service disruptions) in the near-term future.

- Significantly increase the costs of maintaining system security and reliability standards, further driving up electricity prices.

Substantial policy effort is already being allocated to understand and address many of these barriers. Select barriers that are emphasised in this study are ones which are 'cross-sectoral' in nature (e.g. external benefits of green housing design and green urban infrastructure). These barriers appear to have received less attention within the electricity sector policy domain and will require increased coordination and collaboration across traditional sectoral policy boundaries to effectively address.

Furthermore, given the concern about rising electricity prices, communities' attitudes/preferences for heatwave risk (in terms of security and reliability, and how this is reflected in prices) should also be better understood as part of future adaptation policy effort. This is important to ensure that adaptation is efficient and that the sector also appropriately considers the needs of lower-income groups. Inefficiently high electricity costs/prices to meet growing (heatwave-related) peak demand is maladaptation.

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7 Transport

The focus of this chapter is on the rail and road components of the transport sector. These are the components that have been identified in previous assessments (QUT 2010, TCI 2013) to be materially affected by heatwave events.

7.1 Context

The rail network in Victoria radiates from Melbourne with main interstate links to Sydney and Adelaide as well as major lines running to regional centres. As at 2015 there were some 4,221 route-kilometres of open railway line including light rail/tramlines (BITRE 2018). Of this, 462 kilometres is located within the Melbourne metropolitan area and 373 route-kilometres is electrified (BITRE 2018). Most movement on the rail network is passenger traffic, concentrated mostly within the Melbourne metropolitan area.[45] In 2014-15, there were 4.69 billion passenger kilometres travelled within the Melbourne metropolitan area, with 84 per cent (3.96 billion passenger kilometres) of this on heavy rail and 16 per cent (0.73 billion passenger kilometres) on light rail (BITRE 2018). Victoria wide domestic rail freight in 2014-15 was 12.6 billion tonne kilometres (BITRE 2018).

The road network in Victoria has the highest density of any state, servicing population centres spread out over most of the state. As at 2015, there was 145,736 kilometres of total road infrastructure, with 36,417 kilometres (25 per cent) located in urban areas[46] and 109,320 kilometres (75 per cent) located in non-urban areas. Compared to the rail network, both passenger and freight movements on the road network are much higher. In 2014-15, there was 53.7 billion passenger kilometres travelled within the Melbourne metropolitan area (BITRE 2018)[47]. Victoria wide domestic road freight in 2014-15 was 39.6 billion tonne kilometres, with 32 per cent (12.7 billion tonne kilometres) of movements being within the Melbourne urban area (BITRE 2018).

Ownership and management of rail and road network infrastructure within Victoria is complex. The Victorian Government owns most rail and public transport assets (primarily land, rail lines and rolling stock of trains and trams). A series of franchise agreements determines the allocation of these assets to the operators, as well as the key responsibilities for repair and maintenance of the assets. Public road infrastructure is a mix of Federal, State, and Local Governments. There are also two privately owned and operated tollways – Citylink and Eastlink.

7.2 Nature of expected impacts

Heatwave events can cause physical damage to rail (train + tram) and road infrastructure.

Damage to rail infrastructure includes ‘buckling’ of railway lines. Under hot conditions steel rails expand, start to curve, and can become ‘buckled’. Damage to rail infrastructure also includes in-carriage air-conditioning systems and electrical signalling equipment that can malfunction under extreme heat conditions.

Damage to road infrastructure includes ‘bleeding’ or ‘flushing’ of roads - which refers to a stickiness of the road surface. Bleeding/flushing mostly pertains to bituminous sprayed sealed types of roads and is typically a result of excessive bitumen in the road material make-up.[48] In such cases, heat causes the bitumen to rise to the surface and immerse the stones, leading to a removal of bitumen when vehicles run over the surface and consequential damage to road and vehicles (QUT 2010).

When heatwave events occur, and infrastructure assets are damaged, passenger and freight transport services can be negatively impacted. This can be a delay of service or a requirement for users to take an alternative, costlier, route. Where passenger or freight services are time-sensitive (e.g. perishable agriculture products), it can also be a cancellation of service.

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[45] Rail passenger flows are growing rapidly. For the ten years to 2014, heavy rail train patronage increased by 66 per cent (BITRE 2018).
[46] 61 kilometres of this was toll roads (Citylink and Eastlink).
[47] Of this, 88 per cent (47.2 billion passenger kilometres) was passenger cars, 8 per cent (4.59 billion passenger kilometres) was commercial vehicles, 1 per cent (0.40 billion passenger kilometres) was motorcycles, and 3 per cent (1.54 billion passenger kilometres) was busses.
[48] This can also can be due to sealing too often or too soon, embedment into underlying materials or inadequate allowance for traffic.

Further, transport services can be indirectly impacted by heatwave events through electricity service disruptions and higher incidences of passenger health events (e.g. heatstroke of passengers). Electricity disruptions can affect operation of the electrified metropolitan rail network, causing delays and cancellations of (passenger and freight) services in affected areas. They also effect function of CCTV and electrical traffic control elements of the road infrastructure networks, potentially resulting in congestion and slower passenger and freight movements.

The nature of heatwave impacts for the transport (rail and road) sector is summarised in Table 9 below.

Table 9. Types of damages and losses expected in the transport (rail and road) sector

Damages	Losses
Damages to transport (rail + road) infrastructure	Disruptions to passenger and freight service provision[49]

This quantitative analysis will assess losses to the rail and road transport sector pertaining to disruptions to passenger and freight services. Knock-on effects from transport service disruptions on other sectors[50] are (partially) analysed in those sector chapters.

7.3 Sensitivity

The susceptibility of transport services to impacts (losses) from heatwave events is different for the different modes.

Rail (passenger and freight) transport can be described as having a "low sensitivity" to heatwave hazards. As temperatures rise, the likelihood the rail track will not perform to its required level of service increases or, in the worst case, buckling occurs. The trigger point for when the rail track starts to buckle is not precisely known and depends on a number of other factors – including the material of the underpinning rail sleeper (wood versus concrete), whether the tracks have been routinely maintained, and the extent to which the speed of trains (higher speed trains exert higher pressure on tracks) are appropriately managed.[51] A study undertaken by the Queensland University of Technology (2010) following the 2009 heatwave event suggests this threshold temperature is likely to be around 40°C for the Melbourne metropolitan system. When rail lines buckle, the duration of the corresponding service disruption (delay or cancellation) is relatively short. Remedial de-stressing work typically takes place overnight (QUT 2010).

As temperatures exceed 42°C, the likelihood of train air-conditioning systems failing also increases. Newer rolling stock of trains (X'Trapolis and Siemens trains) are designed to operate up to ambient temperatures of 42°C (AECOM 2012). There is also older stock (Comeng trains) which have lower threshold points.[52] These trains are being progressively phased out.

Electricity outages further exacerbate rail service disruptions, especially in the electrified metropolitan service areas. As outlined in textbox below, this was a significant contributor to Melbourne metropolitan passenger service disruptions experienced during the 2009 heatwave event.

Road (passenger and freight) transport can be described as having a "very low sensitivity" to heatwave hazards. Flushing is unlikely to occur unless engineering design of the road is erroneous, the roads are not constructed as designed, or roads are not supported by a vigilant and efficient maintenance regime. Also, as mentioned above, flushing mainly affects bituminous sprayed sealed roads, not roads with asphalt surfacing. Roads within the boundary of the City of Melbourne have high-grade asphalt surfacing. Roads outside this

[49] Attributable to infrastructure damage as well as electricity service disruptions and higher incidences of passenger health events.
[50] For example, loss of perishable agriculture produce due to rail freight service cancellations.
[51] Also, train rail lines are more susceptible than tram rail lines.
[52] Comeng trains are designed to operate up to ambient temperatures of 34.5°C.

boundary tend to be bituminous sprayed sealed roads and are thus marginally more susceptible to damage (QUT 2010).

Effects on road networks from electricity outages (primarily functioning of CCTV and electrical traffic control systems) mostly correspond to the areas that experience outages. For medium intensity heatwave events, where associated electricity outages are expected to be localised, the extent to which electricity disruptions affects road traffic flows is generally minor as road uses can switch to alternative routes in the network relatively easily. However, where heatwave events are very intense and electricity outages affect a wide geographical area (noting this is unprecedented in Victoria), this can be expected to affect entire road network segments and thus cause material congestion and service disruptions.

In early 2009, Victoria suffered through a long and intense heatwave event that materially affected the transport sector. In Melbourne, the EHF index peaked at 122 with temperatures reaching over 43 degrees for three consecutive days.

During this event, there were 29 instances of train rail buckling reported (Osborne & McKeown 2009), extensive failures of air-conditioning systems – primarily among the older stock Comeng trains, and an electrical power failure to the city loop services. More than 750 services out of 2,400 were cancelled – that is, more than one-third of services.

Buckling of tram tracks were reported at Port Melbourne, Airport West and Royal Park. Compared to train tracks however, impacts were minimal with only a few tram services being cancelled. In some cases, trams served as an alternative to failed train services.

Road surfaces were minimally damaged, with less than 1 per cent of roads affected by flushing. Traffic signals at 124 intersections in metropolitan Melbourne (and 3 in regional Victoria) were also reported to be malfunctioning on the afternoon of 30 January - primarily due to electricity outages.

Airports were largely unaffected by the heatwave event. Road traffic flows to major airports were not materially affected. Major airports in the Melbourne region have their own back-up power supply.

Box 3. Case study example of impact in transport sector from 2009 heatwave event

The relationship between heatwave intensity (measured in terms of peak EHF) and transport sector impacts (in terms of economic value add for that sub-sector) is approximated in the 'sensitivity functions' below.

These functions are based on observed impacts from the 2009 heatwave event in Melbourne (QUT 2010).[53] The functions also incorporate a hypothetical heatwave consequences scenario developed to inform Victoria's Preparedness Framework.

[53] For rail, the impact on (annual) value-add is assumed to be the same proportion as the % of train services that are cancelled due to the heatwave event. There has been no differentiation between train and tram as value-add data cannot be readily disaggregated to this level. It is further noted that there was an industrial action/dispute during the 2009 heatwave event that may have further contributed to service cancellations.
For road, the impact on (annual) value-add is assumed to be the same proportion as the % of roads that are affected by flushing. It is noted that this is likely to be overstating impacts to some extent as road uses can generally switch to alternative routes when road impacts are limited to a small segment of network.

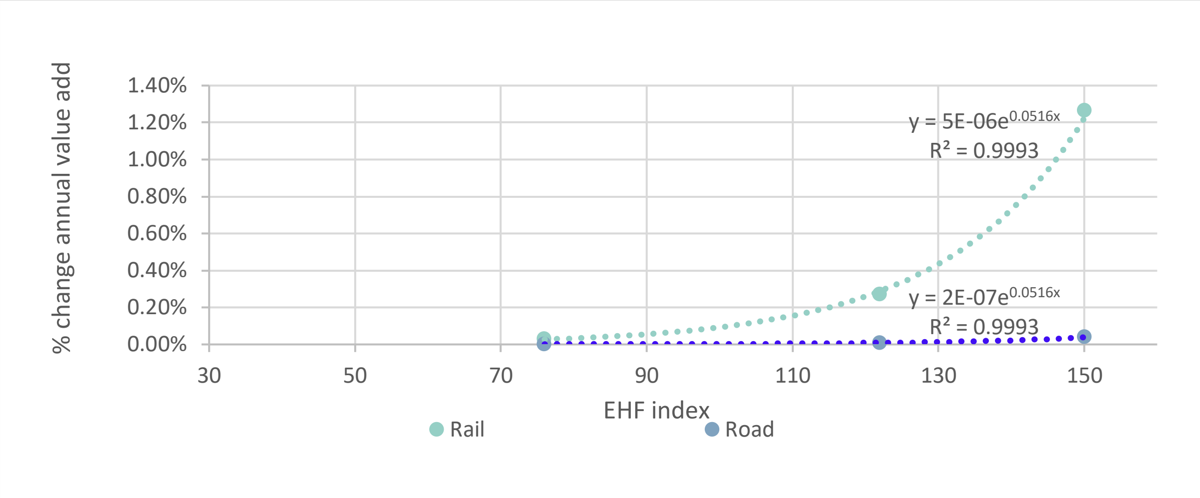

Figure 11 Sensitivity functions for rail and road transport sub-sectors

Note, the above functions do not fully consider the inter-dependencies within the transport system. These relationships are largely location-specific and would require detailed traffic flow data to properly understand.

7.4 Extent of potential impacts

The magnitude of losses for the transport sector are low for severe and extreme levels of heatwave intensity but do increase modestly to around 13 million for the very extreme events. Of this, the rail component makes up the large majority (over 82 per cent) of total impact. See Table 10 for a summary of results.

Table 10. Quantification of loss in the transport network

Sub-sector	Losses ($Millions)		
	'Severe' heatwave event	'Extreme' heatwave event	'Very extreme' heatwave event
Rail	0.02	0.25	10.63
Road	0.00	0.06	2.25
Total	0.02	0.31	12.88

7.5 Probability-weighted extent of impacts

The probability-weighted magnitude of losses for the transport sector is summarised in Table 11. This table also includes impacts for future time periods (2030 and 2050) - assuming vulnerabilities remain at their current levels.

As can be seen, it is the very extreme heatwave events that present the greatest risks for the transport sector. These impacts become more material in the future as the frequency of very extreme level events increases under the effects of climate change.

Table 11 Annual expected impact for transport sector for each heatwave category

Heatwave intensity	2018 Annual 'expected' impact ($M)	2030 (RCP 8.5) Annual 'expected' impact ($M)	2050 (RCP 4.5) Annual 'expected' impact ($M)	2050 (RCP 8.5) Annual 'expected' impact ($M)
'Severe'	0.01	0.02	0.03	0.03
'Extreme'	0.01	0.02	0.03	0.03
'Very extreme'	0.12	0.31	0.31	0.51

7.6 Distribution of impacts

Figure 12 shows the distribution of transport impacts across the different Regional Partnerships in Victoria. Melbourne incurs most loss in absolute terms – by far – reflecting the concentration of rail transport activities in these areas.

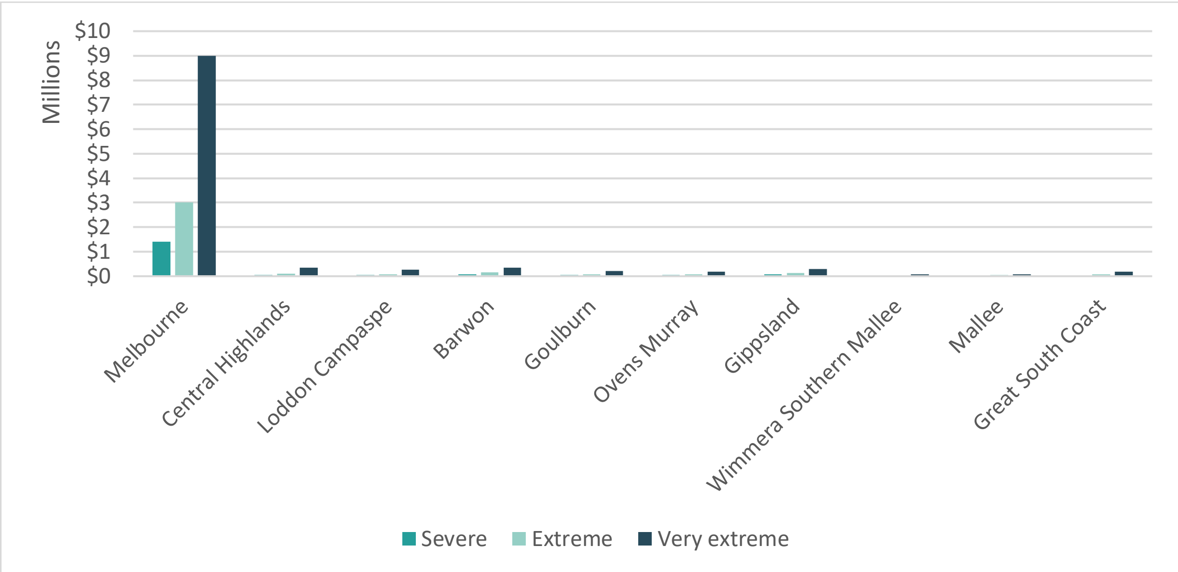

Figure 12 Distribution of transport losses across regional partnership areas

7.7 Barriers to effective adaptation

There are several barriers and impediments that constrain the transport sectors capacity to autonomously manage heatwave risks. Select barriers that have been identified in this study sector are summarised in Table 12 below.

Table 12. Barriers constraining the capacity of the transport sector to adapt to heatwave hazards

i.	Market failures
Information failures	Whilst some organisations are moving to better understand and manage the heatwave risks they face, many transport infrastructure owners and operators (including Local Governments) are focused on maintaining their assets to standards based on historic, not future, climate.

	The Climate Institute (2012) identifies fragmentation of information as one of the key reasons for this.
Market and government failures in electricity sector	Electricity outages are a material cause of metropolitan rail service disruptions during heatwave events. However, the capacity of many rail sector corporations to fully manage these (heatwave-related electricity supply) risks is constrained because they rely on public electricity supply businesses to provide these services and because electricity distribution businesses are natural monopolies (with monopoly power). In the future, road transport is also expected to become more electrified as electric vehicle (EV) technologies further develop. In this way, inefficiencies in the electricity sector present as constraints on the capacity of road transport to adapt to heatwave risks in the future. Market and regulatory/government failures affecting the electricity sector are discussed in the electricity chapter.
Market and government failures in public health sector	Passenger heat-related health incidences are a material cause of passenger rail service disruptions during heatwave events. However, the capacity of transport businesses to fully manage these risks by themselves is constrained by several market and government failures affecting the public health sector (e.g. inadequate public communication and education on heatwave risks). Market and government failures affecting the public health sector are discussed in the health chapter.
External effects of road infrastructure on urban environment	The radiative and thermal properties of road infrastructure materials can have external heat effects on the neighbouring urban environment – contributing to what is sometimes referred to as the 'urban heat island effect'. These effects impose additional costs on the community during heatwave events in the form of higher levels of discomfort and health effects (refer health chapter) - and typically involve increased electricity use for running air-conditioners to help manage this heat (refer electricity chapter). In many cases, the design of urban roads does not fully take these effects/considerations into account.
ii. Policy and regulatory barriers	
Regulatory barriers	Whilst some organisations are moving to better understand and manage the heatwave risks they face, many transport (and electricity) infrastructure owners and operators (including Local Governments) are focused on maintaining their assets to standards based on historic, not future, climate. Regulated entities such as passenger rail services need to demonstrate investments (including in adaptation) are 'prudent and efficient'. Regulators that don't properly accommodate climate extremes are less likely to identify adaptation expenditures as prudent or efficient. The Climate Institute (2012) identifies inappropriate and inconsistent regulation as one of the key reasons for this. Research to identify the specific regulations relevant for the Victorian context has not been undertaken as part of this study.

iii. Governance and institutional arrangements	
Slow progress in integrating climate risk into (state public transport and freight) policy and planning	The Department of Economic Development, Jobs, Transport and Resources (DEDJTR) Victoria coordinates policy for Victoria's public transport and freight. A new agency, Transport for Victoria (TfV) has also recently been established which has a focus to integrate the Victorian transport network. DEDJTR and TfV has recently set up an inter-agency (sustainability) working group tasked with developing a framework to improve the 'sustainability' of the broader Victorian transport system. Climate hazards, and heatwave hazards specifically, will be considered as part of this framework. This sustainability framework is still in its early stages of formation. VicRoads, a separate agency under the transport portfolio, has (appropriately) undertaken its own climate change risk assessment work. This is publicly available online. This assessment does not mention external (inter-dependent) factors that contribute to heatwave risk. Of note, there is no mention of electricity outage impacts or increase demands on services resulting from train service disruptions. Public Transport Victoria (PTV), another agency under the transport portfolio, has recently commissioned a study to more comprehensively understand climate risks that it faces - including heatwaves. This study will be complete later in 2018. VicTrack, the owner of Victorias public transport assets, manages allocation and maintenance of its assets through a series of franchise agreements. In general, the group controlling the asset is required to ensure its proper management. A report prepared by the Queensland University of Technology (2010) on the impacts of the 2009 heatwave event suggest most public transport assets in Victoria are managed to standards based on historic, not future, climate.

7.8 Concluding remarks

The vulnerability of the transport sector to heatwave events is currently low. Within the transport sector, rail transport is relatively more vulnerable.

Existing rail vulnerability is progressively being reduced through upgrades of rolling stock (particularly air-conditioning components designed to operate at higher ambient temperatures) and improvements to tracks (including replacing wooden sleepers with concrete sleepers at select segments).

Residual vulnerability for rail mostly pertains to electricity service and health-related disruptions. Both vulnerabilities are largely outside the powers of control of the transport sector and are best addressed at the source of risk (i.e. electricity and health sectors).

The focus of (heatwave-related) adaptation policy effort in the short-medium term should be on integrating consideration of heatwave risk into mainstream planning and operational processes. This includes processes followed by regulators to assess whether new infrastructure investment proposals are 'prudent and efficient'.

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8 Water

8.1 Context

The Victorian water supply system is connected to the Murray Darling Basin (MDB) system which spans the eastern and southern states of Australia - including Queensland, New South Wales (including Australian Capital Territory), Victoria, and South Australia.

Within Victoria, water supply is managed through the State's water grid - which is a system of rivers, pipes and channels that distribute water for irrigation, urban and environmental needs. The grid has expanded over more than a century and now stretches throughout most of the State (see Figure 13).

Figure 13 The Victorian water grid (DELWP 2015)

A wide range of catchment management authorities, water corporations and private businesses are involved in operation of the grid and, in turn, the provision of water and sewage services. Approximately 7,100 Victorians work within the sector – 0.25% of the State's workforce (ABS 2017).

8.2 Nature of expected impacts

Heatwaves can potentially impact on the water sector in several ways.

One key way is through damage to environmental (ecosystem) assets. If ecosystem assets (e.g. forests) in key water catchment areas are damaged by heatwave events, this would be expected to reduce the water provisioning and water regulation services provided by these assets. In turn, the quantity of water 'produced' by the sector would be reduced and costs of treatment would increase.

Other potential ways the water sector is impacted is through:

- Damages to machinery and equipment (particularly electrical equipment). The high ambient temperatures increase the likelihood of some machinery and equipment overheating, leading to a disruption of services (QUT 2010).
- Electricity outages. If electricity outages persist for an extended period, this can affect operation of water pumps and water treatment equipment, leading to disruption of services.

- Peak demand effects. Like the electricity sector, heatwave conditions affect the water supply system through spikes in water demand – referred to as 'peak demand'. The agriculture sector is a key driver of peak (rural) water demand during heatwave periods (refer chapter 9). If peak demand is not accurately forecasted and actioned as needed, this can result in a supply shortfall during these times (even if farmers have sufficient annual use limits under their water entitlements and/or purchased temporary water allocations). Peak demand also creates higher (water) pressures on distribution networks. If pressure goes above the technical design limits of infrastructure[54], then the system may be required to deliberately limit/slow supply services to avoid damage to infrastructure and broader water losses.[55]

Damages and losses expected in the water sector are summarised within Table 13.

Table 13. Types of damages and losses expected in the water sector

Damages[56;57;58]	Losses
Minor damage to treatment plants, pumping stations and associated infrastructure (i.e. electric motors)	Disruption in water supply services
Damage to ecosystem assets	Higher costs of treatment/production
	Reduced water available/produced

Note, this analysis assesses losses associated with disruption in water supply services only. Knock-on effects from water service disruptions on other sectors are (partially) analysed in those sector chapters.

As explained in the environment sector chapter, there is currently not enough information to understand the impacts of heatwave events on ecosystem assets and hence the reduction of water provisioning and water regulation services.

Also, the effects of peak demand on water supply costs/prices are not quantitatively assessed.

8.3 Sensitivity

Potential damages to ecosystems from heatwaves could cause significant – and possibly long-term/permanent - losses for the water sector. However, as discussed in the environment sector chapter, there are considerable uncertainties with the information currently available on these damages, which precludes quantitative estimation of sensitivity at this stage.

The trigger point for when machinery and equipment start to overheat and underperform varies for each asset. The performance of these assets during heatwave conditions depends on a range of factors, including: the materials used to build the asset, the condition of the asset, whether the asset has been routinely maintained etc. A study undertaken by the Queensland University of Technology (2010) following the 2009

[54] Network infrastructure capacity cannot quickly increase to accommodate loads due to technical (design limits).

[55] It is further noted that, increasing design load limits for distribution infrastructure is very costly.

[56] A report prepared by The Climate Institute (2012) recorded that there was an increase in blue green algae (BGA) growth at open lagoons in one treatment plant during the 2009 heatwave. For potable water supplies, BGA triggers increased treatment and / or temporary supply substitution, which will increase the cost of water supply. However, through consultation for this assessment it was identified that BGA growth is dependent on several conditions and does not necessarily require extreme heat for growth (i.e. anecdotally, BGA has grown in the winter in north eastern Victoria). For this reason, the growth of BGA has not been recorded as a damage during extreme heat.

[57] Pipe cracking was raised as a possible damage during extreme heat. However, it was agreed that pipe cracking is a key concern of the water sector during periods of prolonged dry conditions (i.e. drought) – not necessarily once off extreme heat events. Pipe cracking is largely a function of soil composition (particularly soil moisture), which is not materially impacted by short-term heatwaves (QUT 2010, footnote 8). Therefore, pipe cracking is not considered to be a damage for this vulnerability assessment.

[58] Corrosion in sewers was mentioned during consultation as a possible damage to consider but later cautioned. Corrosion in sewers is exacerbated during prolonged dry periods, which can lead to under performance or failure of water infrastructure and equipment. However, short-term extreme heat is not understood to trigger additional damage and therefore has not impacted this assessment.

Victorian heatwave shows that the threshold temperature for many of the sector's critical assets within metropolitan Melbourne are above 40 degrees Celsius. However, the study highlighted that during this heatwave event the Western Water Treatment Plant was not able to function as designed because one of three aeration blowers overheated and automatically shut down.[59] This led to a reduction in sewage treatment capacity for 4 -5 days, which slightly reduced the volume of recycled water available for customers (QUT 2010). In addition, some minor problems were reported to assets with electric motors, but these were not recorded as influencing service delivery (QUT 2010, TCI 2012).

Electricity outages may contribute to short-term water service disruptions – if outages are experienced for a protracted period. Water utilities typically fill water storages ahead of any heatwave events which gives them enough water for approximately 24 hours of supply without the need for electricity inputs (pers comms John Day, North East Water).

In recent years, North East Water (NEW) opted to change their electricity procurement arrangements to purchase directly from the wholesale market. A key reason for NEW doing this was to receive more information on forecasted NEM supply and demand and thus expected load shedding events and electricity price increases/spikes. To this end, NEW now receive notification a week in advance of any expected peak electricity demand event as well as another notification of this situation on the day of the event. This information has allowed NEW to better prepare and plan for (electricity outages and higher electricity prices associated with) heatwave events. Amongst other things, the heatwave risk management practice of NEW includes:

- To fill water storages ahead of any heatwave events;
- Arrange workflows so they can turn off/minimise electricity intensive activities during the peak demand period; and
- Use lower cost mobile backup generators (@$300/hr) for any high need activities (e.g. operation of water treatment infrastructure) during peak demand electricity (spot) price periods.

Box 4 North East Water's strategies to manage heatwave-related electricity risks

In the time available for this analysis, data was not able to be collected to develop a sound understanding of (heatwave-related) peak demand effects for rural water[60]. For rural water, it is understood that, infrastructure capacity has constrained water supply to farmers in at least one instance in recent times. This was the January 2018 heatwave event whereby capacity constraints at river diverters impeded timely delivery of water to some farmers in the Lower Murray region (pers comms Greg Turner DEDJTR, Hunt 2018).

The sensitivity function developed for the water sector is outlined in Figure 14 below. This sensitivity function has been informed by consultations with water sector stakeholder, the impacts of the 2009 heatwave event (QUT 2010), as well as a hypothetical consequence scenario developed as part of the Victorian Preparedness Framework.

[59] The blowers provide oxygen as part of the nitrogen removal process and have been designed to all operate concurrently.
[60] Consultations with DELWP and urban water utility stakeholders indicate that heatwave related peak demand does not result in water service delivery disruptions for urban water – above and beyond any existing constraints (e.g. existing water restrictions).

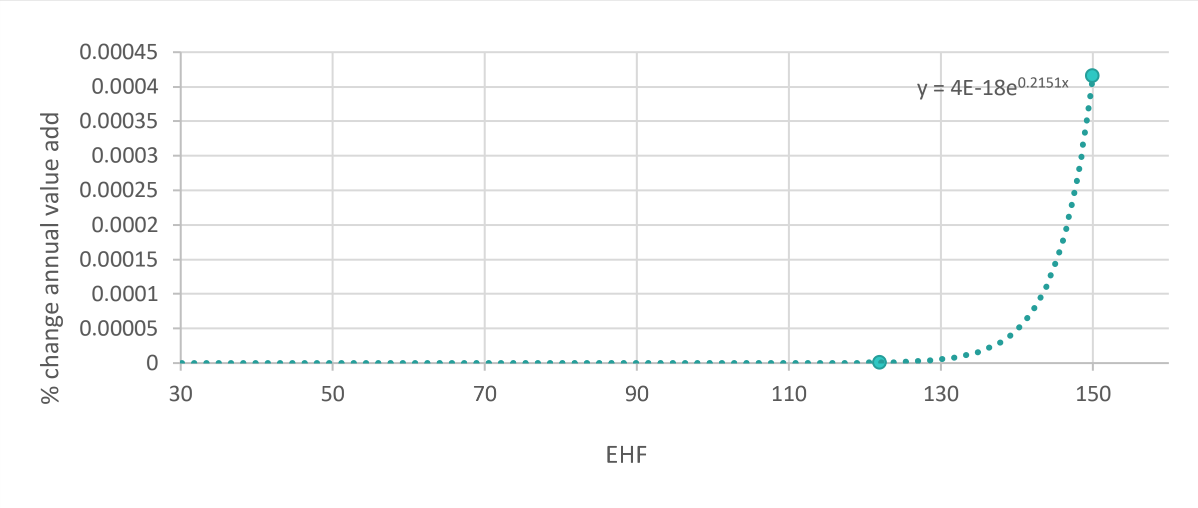

Figure 14 Sensitivity function for the water sector

8.4 Extent of potential impacts

The magnitude of quantified losses for the water sector are low. There are no estimated impacts for severe and extreme level heatwave events. Only very extreme level events show an impact, albeit very small at around $91,000. See Table 14 for a summary of results.

Table 14. Quantification of loss in the water sector

Sub-sector	Losses ($000s)		
	'Severe' heatwave event	'Extreme' heatwave event	'Very extreme' heatwave event
Water	0	0	0.09
Total	0	0	0.09

It is highlighted that these results do not account for the (potentially significant and long-term) loss of water provision and water regulation services associated with potential heatwave-attributable degradation of ecosystem assets.

They also do not fully capture the service disruptions relating to potential limitations in rural water supply infrastructure capacity to accommodate peak (rural) water demand flows.[61]

When these factors are taken into consideration the impacts on the water could potentially be much higher.

8.5 Probability-weighted extent of impacts

The probability-weighted magnitude of losses for the water sector is summarised in Table 15. This table also includes impacts for future time periods (2030 and 2050) - assuming vulnerabilities remain at their current levels.

[61] Detailed information on this aspect was not able to be collected in the time available for this analysis.

Table 15 Annual expected impact for water sector for each heatwave category

Heatwave intensity	2018 Annual 'expected' impact ($M)	2030 (RCP 8.5) Annual 'expected' impact ($M)	2050 (RCP 4.5) Annual 'expected' impact ($M)	2050 (RCP 8.5) Annual 'expected' impact ($M)
'Severe'	0	0	0	0
'Extreme'	0	0	0	0
'Very extreme'	0	0	0	0

For the reasons outlined in sections 8.3 and 8.4 above, caution should be exercised when interpreting the above results. These results do not capture potential effects relating to damage to ecosystem assets (water catchments) or rural water supply disruptions relating to potential limitations in rural water supply infrastructure capacity to accommodate peak (rural) water demand flows.

8.6 Distribution of impacts

Figure 15 illustrates the estimated impacts across the different Regional Partnerships in Victoria. The Melbourne regional partnership zone contributes 88% to impacts from very extreme heatwave events and the Barwon regional partnership area accounts for 6%.

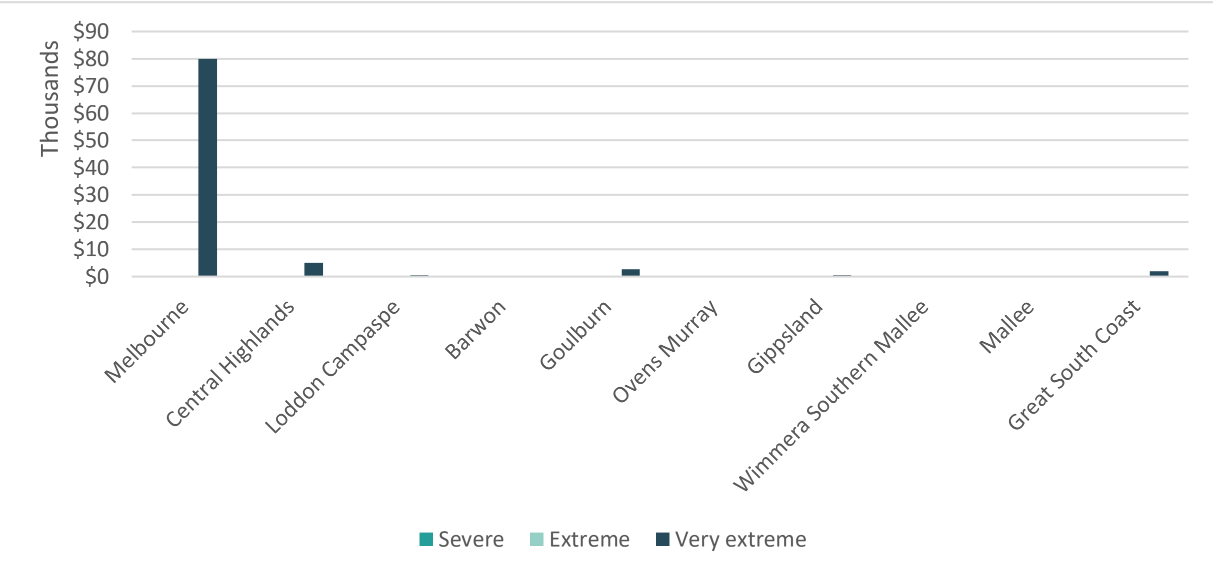

Figure 15 Distribution of water losses across regional partnership areas, by heatwave intensity level

For the reasons outlined in sections 8.3 and 8.4 above, caution should be exercised when interpreting the above results. These results do not capture potential effects relating to damage to ecosystem assets (water catchments) or rural water supply disruptions relating to potential limitations in rural water supply infrastructure capacity to accommodate peak (rural) water demand flows.

If rural water supply disruptions are material the (water sector) impacts on regional areas would be expected to be more substantial.[62]

[62] Note, the flow through impacts of water supply disruptions on the agriculture sector are considered in the agriculture sector analysis.

8.7 Barriers to effective adaptation

The above analysis indicates that the key dimension of heatwave risk that could materially impact on the water sector pertains to damage to ecosystem assets. There are a range of barriers and impediments that constrain the capacity of individuals/businesses/Government to effectively manage heatwave risks to ecosystem assets. Select barriers are outlined in the Environment sector chapter.

Importantly, the water sector – or more precisely the current functioning of the water sector – may act as a barrier constraining other sectors capacity to adapt to (changing) heatwave hazards. Water is a critical input to many adaptation responses. For example, many agriculture sub-sectors rely on irrigation measures to help mitigate heatwave stress on crops and livestock. Also, watering is an important risk management response for maintaining the health of public greenspaces (which, in turn, is important for urban cooling and thus health and electricity). To the extent that there are barriers constraining the efficient allocation of water resources in Victoria and the broader Murray Darling Basin system[63], this is expected to be an impediment affecting capacity of other sectors to use water inputs to help manage their heatwave risks.

This underscores the importance of further implementing reforms under the National Water Initiative (NWI), including effective implementation of the Murray Darling Basin Plan and ensuring that the regulatory asset base for service providers incorporates key assets (e.g. pumps) that are capable of operating in high temperature environments.

8.8 Concluding remarks

The vulnerability of the water sector to heatwave events is not clear as the potential (biophysical) impacts on ecosystem assets (which provides water provisioning and water regulation services) are currently not well understood. Given ecosystem service losses could be substantial and long-term, vulnerability of the water sector could potentially be medium to high.

A key focus of (heatwave-related) adaptation policy effort should be on better managing ecosystem assets for heatwave (and other climate-related risks). The water sector has a key role in inputting to these management planning decisions.

Another area that merits further consideration pertains to rural water supply infrastructure capacity to deliver peak (rural) water demand flows. Data to adequately understand this aspect was not able to be collected in the time available for the analysis. These effects are potentially important – especially for the agriculture sector.

Importantly, inefficient functioning of the water sector generally serves as a barrier constraining other sectors capacity to adapt to (changing) heatwave hazards. Reforms to improve the management of water resources should thus be progressed as part of the broader policy effort to adapt to changing heatwave hazards.

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[63] For example:

- lack of understanding of complexity of water entitlements and trade frameworks
- other barriers affecting timely trade of water entitlements and temporary water (including across state boundaries)
- inefficient water pricing
- water restrictions

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9 Agriculture

9.1 Context

Victoria is an important agricultural production area for Australia. The Australian Bureau of Statistics' data indicate that Victorian agriculture industry contributes over 50% of all dairy, almonds and non-wine grapes produced in Australia (ABS 2017a). Agriculture is a key contributor to the state's economy and it is also important for the prosperity of rural and regional areas. There are 29,661 agricultural businesses that employ an estimated 91,000 people in Victoria (DEDJTR 2018).

Over a 5-year period commencing in 2012 the agriculture, forestry and fishing industry has contributed an estimated $8.7 billion (ABS 2017b) in value added to the state economy.[64] The annual contribution has been constant with an average contribution of 2.4% to the Gross State Product in the last five years.

Based on value add estimates, the combination of sheep, beef cattle and grain farming are the largest contribution to Victoria at $2.9 billion, followed by dairy at $1.7 billion. Corangamite-South, Moyne-East, Numurkah, Foster and the Shepparton Region-West are the largest economic contributors for the dairy sector in Victoria at $151 million, $103 million, $88 million, $73 million and $66 million, respectively. Southern Grampians contributed the highest value for sheep, beef cattle and grain farming at $135 million in 2016.

9.2 Nature of expected impacts

Farmers can be affected by heatwaves in diverse ways. Impacts are driven by the different climatic regions, type of crops and livestock farmed, and access to heatwave management options.

Impacts on livestock from heatwave stress include stock deaths, reduced fertility, lower milk yield, and increased input requirement (Nidumolu et al. 2010; Thornton et al. 2009).

Impacts on (perennial and annual) crops from heatwave stress include damage to trees/vines, yield loss, damaged products, reduced product quality, and increased input requirement (Goodwin et al. 2017; Lolicato 2011; Webb et al. 2009). A crop type particularly impacted by previous heatwaves is grapes. The specific effect on grape vines has included stalled development, leaf burn, leaf drop, berry sunburn, berry 'bagging' and berry shrivel (Webb et al. 2009). Another example of crop type commonly impacted is apples and pears. These crops suffer sunburn browning and necrosis leading to reduced product output and/or quality (Goodwin et al. 2017).

Figure 16 Severe sun burn damage on an apple in Victoria's Goulburn Valley (A) and a sunburnt pear after two days of a heatwave, photo taken by Henry Schneider on 9th January 2009-two days after the 2009 heatwave (McCaskill et al. 2014)

[64] Based on returns to labour and capital from the agriculture sector using Gross State Product (ABS 2017b) and 2016 census employment data (ABS 2016c).

Heatwaves also affect the health and productivity of farm workers. As outdoor workers, farm labourers tend to be less productive during these periods. The loss of labour productivity affects farm outputs and incomes. The nature of heatwave damages and losses to the agriculture sector is summarised in Table 16.

Table 16 Types of damages and losses expected in the agriculture sector

Damages	Losses
Animal (stock) deaths Damage to fruit trees/vines (stock)	Loss of production (quantity and quality) Higher input costs Labour productivity losses

* Specific sub-sectors covered by losses are outlined in Table 17

Quantified losses for the agriculture sector include loss of fruits/vegetables/seedlings, milk output, weight/meat loss, poorer animal health and labour productivity losses. The quantitative analysis does not include higher input costs.

The selection of sub-sectors for analysis was driven by expected impacts (i.e. focus was on sub-sectors expected to be most impacted) and data availability.

9.3 Sensitivity

The agriculture industry is considered as 'highly' sensitive to heatwaves, including 'severe' level heatwave events which currently occur once every two years on average. Accordingly, many farmers have some risk management practices in place to mitigate the impacts of heatwaves.

The sensitivity to extreme temperatures is largely driven by different climate conditions, animal and plant heat thresholds. Heatwaves that occur during a drought year are more devastating because a drought year limits heatwave management options (Webb et al. 2009).

While it is difficult to establish a precise relationship between physical losses and temperatures, impacts from previous heatwave events can be used as a guideline for current sensitivity. Examples of information that provide an indicator of sensitivity include:

- Reported losses for grape production attributable to the 2009 heatwave event ranged from 10% to complete loss of crop (Mackay 2009).
- Production losses for pears and apples following the 2009 heatwave event were reported to be between 30 and 70 per cent (Thomson et al. 2014). This loss was due to a combination of fruits that were damaged and not picked and those that were picked but were sold for juicing as they were of lower quality.
- After three consecutive days with maximum temperatures ranging from 38 to 42.5°C in northern Victoria, a dairy farm near the town of Cohuna had 8% drop in milk production (Henty and Griffith 2017; BOM 2017).[65] This drop was immediately followed by an upward trend in milk production as the cows started recovering from the heatwave.

There are also regulations for workers at extreme temperatures which can affect the sector's susceptibility to heatwaves. Even outside of these regulations, it is expected that there will be some heat-related productivity losses. Farm work is mostly undertaken outdoors in the field. As a result, workers are very exposed to

[65] Milk production underwent a downward trend from 18th to 20th Dec (inclusive) when temperatures rose to maximums of 38-42.5°C before commencing an upward trend when temperatures dropped to 27°C and remained under 35°C for the next 4 days. Temperature data based on records from Kerang VIC weather station-the nearest weather station (BOM 2017).

heatwave impacts. Farm workers can be classified as labourers working under moderate to high physical exertion.

The relationship between heatwave intensity and the different agriculture sub-sectors is approximated in the 'sensitivity functions' below. The functions are based on past events from 2009 and 2015 and/or informed by existing guidelines and regulations for different sub-sectors.[66] Labour productivity components are based on estimates from Zander et al (2014)[67]. Sensitivity functions for other sub-sectors were not estimated due to lack of data.

[66] Estimating the relationship between an heatwave intensity and impacts on agriculture production/value add is difficult because of (1) the many variables (e.g. time of year at which heatwave event occurs) and factors that interact to affect the extent to which heatwave events result in losses for each of the different agricultural commodities, and (2) lack of readily available scientific studies and impact assessments to inform these relationships. Key information and assumptions used to approximate sensitivity functions for each of the sub-sectors were:

- Impacts on apples and pears was informed by various reports on estimated loss including Thomson et al. (2014) and (Goodwin et al (2017).
- Losses for viticulture relied on estimates reported in QUT (2010).
- Dairy losses estimates relied on a case study results from Henty and Griffith (2010)
- Poultry loss were estimated using the Bureau of Animal Welfare's (DEDJTR 2017) code of accepted farming practice for the welfare of poultry.
- Pig farming losses were based on the pig welfare standards and guidelines (DEDJTR 2012).
- All remaining livestock (and livestock combined with grains) relied on milk production losses as a proxy for losses. The logic for the assumption is that the health/condition of other livestock is similarly impacted by heatwaves as dairy cows.
- All remaining crops and of plants losses relied on apples and pears impacts (vegetables) and grapes (floriculture-outdoor and nursery-outdoor) – as specific impact information for these crops does not exist and/or could not be located for this study. In cases where the sub-sector is assumed to have better mitigation practices only a portion of the losses is applied to these remaining sub-sectors.

[67] Labour productivity losses were based on the finding from Zander et al. (2013) that outdoor workers were 35% less productive for an estimated 5 days per annum from the 2014 heatwave event. This estimate was extrapolated for other heatwave intensity levels in line with the maximum temperature and number of days expected, on average, for EHF levels higher and lower than the 2014 event. The same labour productivity affects were applied across all agricultural sub-sectors captured in this analysis. It was further assumed that most labour productivity impacts would translate to a complete loss of production (i.e. capital productivity is also zero during these times as there are no workers to oversee/operate them). To the extent that that this is incorrect for some farming operations, the results overstate sensitivity/impacts.

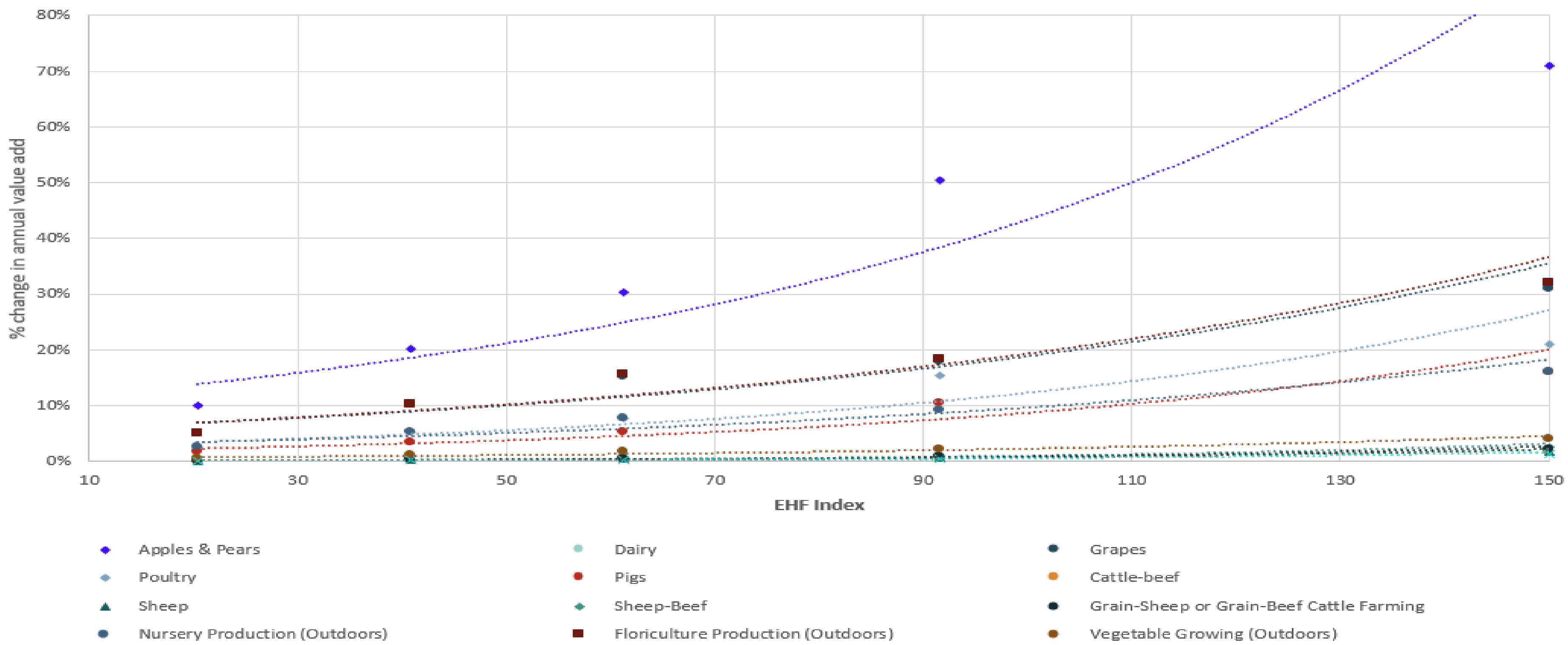

Figure 17 Sensitivity functions for the agriculture sector

The equations and R^2 values for the functions displayed are listed below:

Apples & pears: $y = 0.1036e^{0.0143x}$ $R^2 = 0.8849$
Dairy: $y = 0.0008e^{0.0219x}$ $R^2 = 0.9293$
Grapes: $y = 0.0536e^{0.0126x}$ $R^2 = 0.8844$
Poultry: $y = 0.0254e^{0.0158x}$ $R^2 = 0.8876$
Horses: $y = 0.0007e^{0.0215x}$ $R^2 = 0.9241$

Pigs: $y = 0.0165e^{0.0167x}$ $R^2 = 0.9142$
Cattle-beef: $y = 0.0008e^{0.0219x}$ $R^2 = 0.9293$
Sheep: $y = 0.0008e^{0.0219x}$ $R^2 = 0.9293$
Sheep-beef: $y = 0.0011e^{0.0225x}$ $R^2 = 0.9335$

Grain-sheep/grain beef: $y = 0.001e^{0.0223x}$ $R^2 = 0.932$
Nursery (outdoors): $y = 0.027e^{0.0128x}$ $R^2 = 0.8866$
Floriculture (outdoors): $y = 0.054e^{0.0128x}$ $R^2 = 0.8866$
Vegetables: $y = 0.0058e^{0.0138x}$ $R^2 = 0.899$

9.4 Extent of potential impacts

The extent of the potential impacts on agriculture sub-sectors from heatwave events are summarised in Table 17.

Table 17 Quantification of the loss in the agriculture sector

Sub-sector	Losses ($Millions)		
	'Severe' heatwave event	'Extreme' heatwave event	'Very extreme' heatwave event
Apples/Pears	9.42	17.12	45.93
Cattle Beef	1.29	3.38	13.26
Dairy	2.09	5.45	20.04
Floriculture production (outdoors)	9.42	17.56	42.02
Grain sheep/beef[68]	0.54	1.59	5.39
Grapes	15.92	28.62	47.72
Horses	0. 13	0. 32	1.43
Nursery Production (outdoors)	12.24	22.31	53.04
Pigs	1.61	2.95	9.10
Poultry	8.38	16.39	47.12
Sheep	0.05	0.14	0.46
Sheep – Beef	0.37	1.14	4.29
Vegetable growing (outdoors)	3.52	6.36	15.41
Total	**64.97**	**123.31**	**305.21**

The overall magnitude of losses to the agriculture sector is estimated to be very high for all heatwave intensity scenarios examined. Even at the severe heatwave level, the losses are substantial at approximately $65 million for the sub-sectors analysed.

Grapes are found to be the most vulnerable sub-sector to severe and extreme level events, followed by outdoor nurseries, floriculture, apples/pears, and poultry. For very extreme level heatwave events, most sub-sectors are majorly impacted with apples/pears, dairy, floriculture, grapes, nursery production, poultry and vegetables all showing impacts greater than $15 million. Very limited empirical data for nurseries, floriculture production, beef, sheep and horses could be located for this analysis. There is therefore low confidence in those sub-sectors' results.

9.5 Probability-weighted extent of impacts

The probability-weighted magnitude of losses for the agriculture sector is summarised in Table 18. This table also includes impacts for future time periods (2030 and 2050) - <u>assuming vulnerabilities remain at their current levels</u>.

As can be seen, it is the severe level heatwave events that present the greatest risks for the agriculture sector. These level events occur regularly now and are expected to become even more common in the medium to long term future under the effects of climate change.

[68] Note this grouping of sub-sectors was done because the Census industry of employment grouping – which was used to 'generate' value add data (refer section 3.3) – does not include a stand-alone grain sub-sector.

Table 18 Annual expected impact for transport sector for each heatwave category

Heatwave intensity	2018 Annual 'expected' impact ($M)	2030 (RCP 8.5) Annual 'expected' impact ($M)	2050 (RCP 4.5) Annual 'expected' impact ($M)	2050 (RCP 8.5) Annual 'expected' impact ($M)
'Severe'	31.84	63.91	71.06	84.26
'Extreme'	4.80	9.36	10.21	13.73
'Very extreme'	2.65	7.08	6.99	11.50

9.6 Distribution of impacts

Figure 18 illustrates the estimated impacts across the different Regional Partnerships in Victoria. The high value for the Greater Melbourne area is an outcome of the demarcation of the regional partnerships. In this instance the Melbourne Regional Partnership covers the Melbourne metropolitan area as well as some rural and/or high value agricultural areas such as the Yarra Ranges and Whittlesea. These high values are particularly driven by the outdoor nursery and floriculture sub-sectors in Yarra Ranges, Wyndham, and Mornington Peninsula LGAs. Whittlesea LGA also has significant mushroom growing activities (part of the vegetable sub-sector). There is also significant beef and dairy cattle farming in the Cardinia LGA.

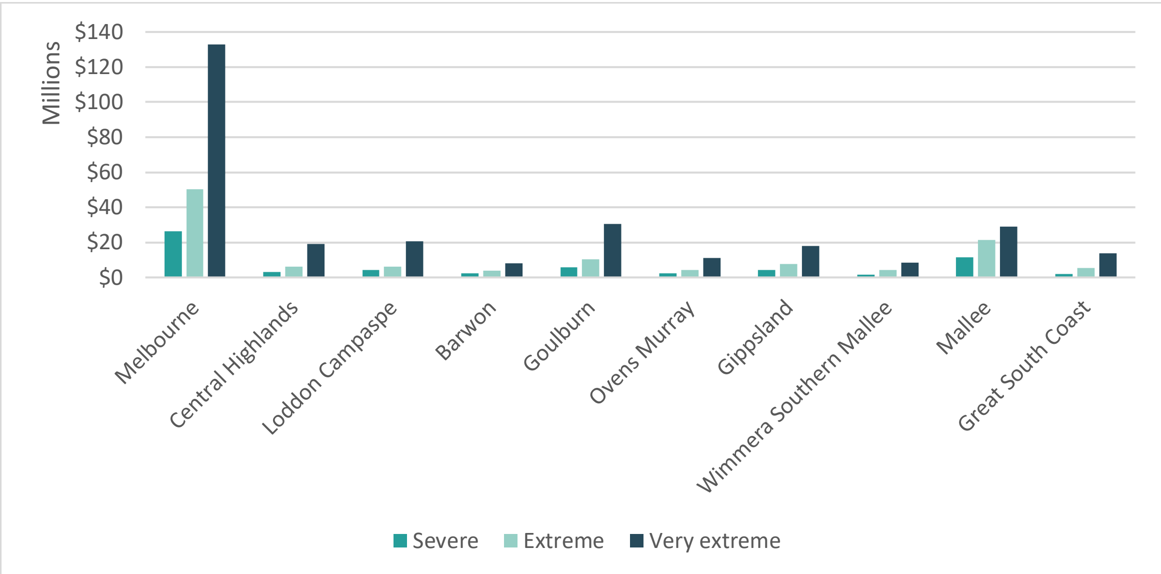

Figure 18 Distribution of agriculture losses across regional partnership areas, by heatwave intensity level

9.7 Barriers to effective adaptation

There are several barriers and impediments that constrain the agriculture sectors capacity to manage heatwave risks. Select barriers that have been identified in this study sector are summarised in

Table 19 below.

Table 19 Summary of key barriers constraining adaptation in the agriculture sector

Market and policy failures	
Information failures	There appears to be a lack of appropriate short-term forecasting information available for farmers to inform heatwave risk management strategies. Farmers typically require information on both temperature and humidity levels[69], however relevant indices are not immediately available to farmers so that they can take effective action to manage heatwave risks. Further, current limitations on down-scaled climate modelling constrains the accuracy of medium term climate information that farmers can use as part of longer-term planning and investment decisions. It is understood that the DEDJTR in collaboration with the University of Melbourne and Bureau of Meteorology (BoM) have recently started a new project entitled "Forewarned is Forearmed" which aims to improve forecasting products for climate extremes - including for heatwaves.
	There appears to be a lack of publicly-available scientific research on heatwave thresholds for some livestock and crop varieties (e.g. floriculture) in the Victorian context. This information is needed to further understand the nature and extent of impacts from heatwave events – and to inform longer-term planning and investment decisions. Similarly, although not examined as part of this study, there is also likely to be a lack of publicly-available scientific research on heatwave-'smart' farming techniques for some livestock and crop varieties. Further analysis is warranted (by DEDJTR) to further understand what the key gaps are and what are the highest priority needs are for publicly-funded research and development (across sub-sectors) going forward.
Market and government failures in the water sector	Watering is an important heatwave risk management strategy for livestock and crops. This applies to both dryland and irrigation farming. As outlined in the water sector chapter, demand for (rural) water increases during heatwave event periods – and can contribute to spikes in water demand if heatwaves are sufficiently intense (i.e. 'peak water demand'). If peak water demand is not accurately forecasted and actioned as needed, this can potentially result in a supply shortfall during these times (even if farmers have sufficient annual use limits under their water entitlements and/or purchased temporary water allocations). Peak demand also creates higher (water) pressures on distribution networks. If pressure goes above the technical design limits of infrastructure[70], then the system may be required to deliberately limit/slow supply services to avoid damage to infrastructure and broader water losses. Water delivery service disruptions in turn constrain farmers capacity to implement (water-based) heatwave risk management strategies in a timely fashion – resulting in losses. Further, inefficient functioning of the water sector generally serves as a barrier constraining the agriculture sectors capacity to adapt to (changing) heatwave hazards. For example, barriers constraining trade of entitlements and temporary

[69] For example, Nain and Fawcett (2015) use the Excess Heat Factor and Nidumolu et al. (2010) use Temperature Humidity Index to measure heatwave severity.
[70] Network infrastructure capacity cannot quickly increase to accommodate loads due to technical (design limits).

	water would be expected to result in water resources being (mis)allocated to lower value uses – leaving less water available for heatwave risk mitigation uses of high value crops. Reforms to improve the management of water resources should thus be progressed as part of the broader policy effort to adapt to changing heatwave hazards. The agriculture sector has a substantial and active role to play in informing/shaping policy making and planning of Victoria's water resources and water resources in the Murray Darling Basin more broadly.

9.8 Concluding remarks

The vulnerability of the agriculture sector is currently very high. Severe level heatwave events present the greatest risks for the agriculture sector. These level events occur regularly now and are expected to become even more common in the medium to long term future under the effects of climate change.

To reduce vulnerability, adaptation policy effort should focus on reducing barriers constraining the sectors capacity to adapt. These include several (public) information-related barriers as well as barriers which affect the efficient management and allocation of water resources (needed for adaptation responses).

More in-depth sectoral analysis is warranted to help further focus and prioritise (heatwave-related) research and development efforts (to address information barriers) within the sector. This can include a more detailed assessment of the heatwave risks in the different sub-sectors[71], building on the initial analysis done here.

Barriers pertaining to water resource management will require careful co-ordination and collaboration across different sectoral agencies to effectively address. It will also require significant consultation and engagement with community stakeholder groups (including farmers).

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10 Construction

10.1 Context

The construction sector is a major component of the State economy, providing employment for over 225,000 Victorians (or 8.3% of the working population) (ABS 2017) – the fourth largest industry behind health care, retail and education (ABS 2017) – and contributing $28 billion value add in 2015-16 (7.8% of GSP) (ABS 2017).

A large proportion of this activity is concentrated in the Melbourne metropolitan area.

10.2 Nature of expected impacts

Heatwaves impact the construction sector in several ways. The key way is through reduced labour productivity. Other potential ways also include direct physical damage to machinery and equipment, disruptions related to and electricity service outages, and disruptions related to (heatwave-related) impacts on transport links.

Heatwaves affect the health and productivity of construction workers. As outdoor workers, construction labourers tend to be less productive during these periods (Wen and Chan 2017 Related to this, occupational health and safety requirements or via other instructing guidelines (e.g. SafeWork 2012) or union policies (e.g. CFMEU 2015, ACTU 1998) also restricts labour inputs. The loss of labour productivity affects construction outputs.

Direct physical damages to sector assets during heatwaves are likely to be confined to machinery and equipment (particularly electrical equipment). The high ambient temperatures increase the likelihood of machinery and equipment overheating, leading to a reduction in output. In some cases, equipment used within the construction sector will have maximum safe operating temperatures above which the assets either automatically reduce output or shut off to guard against damage. As such, along with possible asset damage, impacts may be experienced within the sector due to a reduction in production associated with equipment damage. These temperature thresholds will often be higher than worker-related thresholds, meaning the worker-related thresholds are the driver of economic losses.

The construction sector can also be impacted by heatwave events through electricity service disruptions. Electricity disruptions affect operation of some machinery and equipment that is powered by electricity, causing production to slow or halt in affected areas. Heatwaves can further lead to an increase in peak demand electricity prices, contributing to higher costs of construction (ISR 2010).

In addition, disruptions to the transport network associated with heatwave events may impact the delivery of materials used for construction. Damages and losses expected in the construction sector are highlighted within Table 20.

Table 20 Types of damages and losses expected in the construction sector

Damages	Losses
Damage to select machinery and equipment (particularly electrical).	Lower production/construction output
	Higher costs of production

10.3 Sensitivity

The construction sector is considered 'highly sensitive' to heatwaves. The level of sensitivity is directly related to intensity and duration of the heatwave event – with a greater intensity and duration leading to impacts of greater magnitude.

The sensitivity of this sector is primarily driven by labour productivity effects. Construction workers are among the most vulnerable population to heat stress as a majority of their work is undertaken outdoors, leaving them highly exposed to the effects of heatwaves (Wen and Chan 2017).

The Victorian Occupational Health and Safety Act (2004) does not specifically mention when work on site should cease due to extreme heat but it does convey a power to WorkCover to make guidelines (s 12). WorkCover provides guidance about working in heat but does not specify when certain actions should be triggered (WorkSafe 2012). However, several policies prepared by industry unions exist to provide recommendations to construction operations about working during extreme heat conditions (see CFMEU 2015 and ACTU 1998).

Given the physical nature of their job, construction workers take breaks during periods of high ambient air temperature – a process encouraged by WorkSafe Victoria – to reduce exposure to heat related illness and injury. More specifically, the CFMEU stipulate that work on site should cease and workers should leave the site when the temperature reaches 35 degrees Celsius (CFMEU 2015).[72] The CFMEU policy has widespread application, which significantly affects the composition of the sensitivity function depicted in Figure 19. Even at lower heatwave intensities the CFMEU 'cease work policy' may operate given that the policy requires the ambient air temperature at that moment to be 35 degrees Celsius or greater compared to the calculation of EHF (which is based on a three-day-averaged daily mean temperature).

Electricity service disruptions also contribute to losses to a minor degree - within areas that experience outages. Road network disruptions from heatwaves are not expected to materially influence construction as there are likely to be methods to work around transport disruptions via alternative modes of transportation – especially considering freight of most construction materials are not time-sensitive.[73]

The sensitivity function for the construction sector is shown in Figure 19. The function has been developed by approximating labour productivity impacts based on the CFEMU (2015) cease work policies.[74]

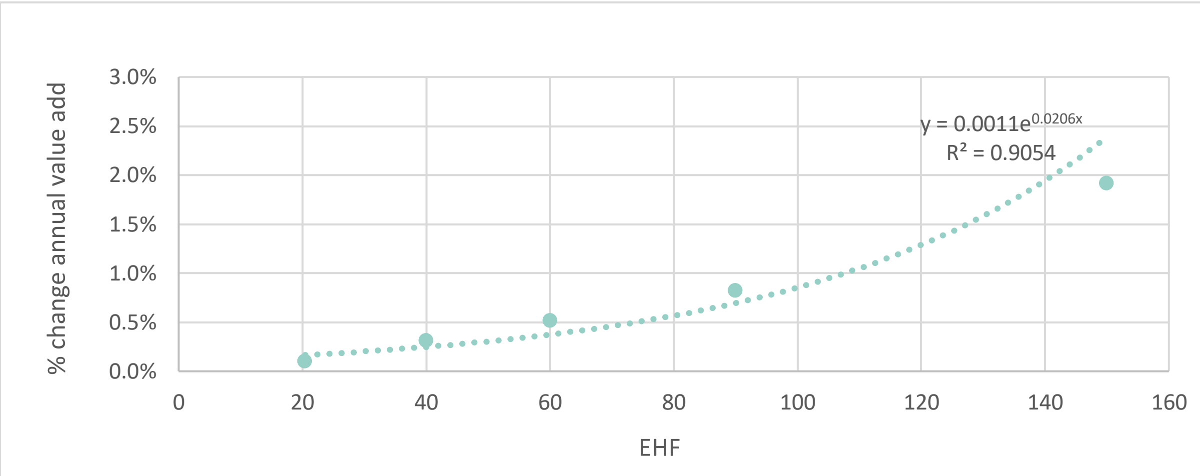

Figure 19 Sensitivity function for the construction sector

[72] Other policies prepared by other unions specify breaks (of variable length given certain temperatures) to ensure that workers' have a chance to rest and cool down (see ACTU 1998 for an example).
[73] Even with generous assumptions the transport sector does not appreciably affect the sensitivity function.
[74] The effects of labour productivity reductions on construction (% change to construction) during heatwave events were derived from the CFMEU (2015) policies. The function was developed by approximating the duration for which the policy would be triggered, assuming an exponential function shape. An analysis of the relationship between EHF intensity and ambient air temperature had to be undertaken to inform this approach.

10.4 Extent of potential impacts

The magnitude of losses for the construction sector are ‘high’ for severe and extreme levels of heatwave intensity and increase significantly to approximately $445 million for the very extreme events. See Table 21 for a summary of results.

Table 21 Quantification of loss in the construction sector

Sub-sector	Losses ($Millions)		
	‘Severe’ heatwave event	‘Extreme’ heatwave event	‘Very extreme’ heatwave event
Construction	38.26	102.98	445.13
Total	38.26	102.98	445.13

These results should be treated with a degree of caution given the lack of directly observed impact data for this sector from heatwave events. Further confidence in the results can be achieved by monitoring effects from heatwave events, refining the analysis by splitting the sector into sub-sectors, and undertaking a more in-depth examination into the realities of lost labour productivity in the construction sector.

> “Global warming is bringing more frequent and severe heat waves, and the result will be serious for vulnerable populations such as construction workers. Excessive heat stress has profound effects on physiological responses, which cause occupational injuries, fatalities and low productivity. Construction workers are particularly affected by heat stress, because of the body heat production caused by physically demanding tasks, and hot and humid working conditions.” (Wen and Chan 2017)

Box 5. An uncomfortable reality for the future of the construction worker

10.5 Probability-weighted extent of impacts

The probability-weighted magnitude of losses for the construction sector is summarised in Table 22. This table also includes impacts for future time periods (2030 and 2050) - assuming vulnerabilities remain at their current levels.

Table 22 Annual expected impact for construction sector for each heatwave category

Heatwave intensity	2018 Annual ‘expected’ impact ($M)	2030 (RCP 8.5) Annual ‘expected’ impact ($M)	2050 (RCP 4.5) Annual ‘expected’ impact ($M)	2050 (RCP 8.5) Annual ‘expected’ impact ($M)
‘Severe’	19.13	38.39	42.69	50.62
‘Extreme’	4.12	8.03	8.77	11.79
‘Very extreme’	4.05	10.79	10.66	17.54

As can be seen, it is the severe level heatwave events that present the greatest risks for the construction sector. These level events occur regularly now and are expected to become even more common in the medium to long term future under the effects of climate change. In the future, extreme and very extreme level events also present as very high risks. All intensity level heatwave events will be important for the construction sector to manage.

10.6 Distribution of impacts

The figure below illustrates the estimated impacts across the different Regional Partnerships in Victoria. The results indicate that construction in Melbourne suffers the greatest total loss (at approximately $30.2M for 'severe' heatwaves), as expected given that most of the State's construction activity occurs within this zone. The Barwon regional partnership zone is the next biggest contributor (at approximately $1.6M for 'severe' heatwaves) with Gippsland third (at approximately $1.4M for 'severe' heatwaves). Wimmera Southern Mallee is the smallest total contributor (at approximately $0.26M for 'severe' heatwaves).

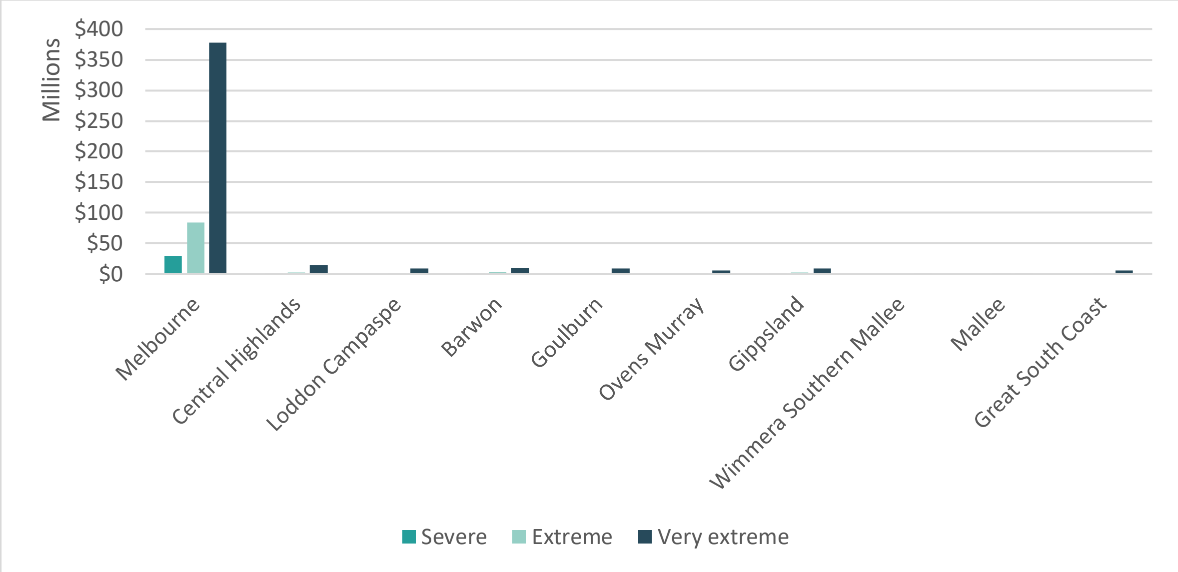

Figure 20 Distribution of construction losses across regional partnership areas, by heatwave intensity level

10.7 Barriers to effective adaptation

There are several barriers and impediments that constrain the construction sector's capacity to autonomously manage heatwave risks. Select barriers that have been identified in this sector are summarised in Table 23 below.

Table 23 Barriers constraining the capacity of the construction sector to adapt to heatwave hazards

i.	Market failures
Information failures	It is likely that a lack of understandable medium-term climate forecasting information – and what this means for construction operations - constrains construction businesses to adapt to heatwave risks. For example, a lack of information and knowledge about how likely 'extreme' heatwave events will be in 10 years time may impede businesses ability to design new processes that are 'heatwave smart' (i.e. earlier start times to complete more work before the temperature reaches 35 degrees Celsius).
Market and government failures in electricity sector	Electricity outages resulting from heatwave events may cause disruption to construction; yet, the capacity of many construction sector businesses to fully manage these (heatwave-related electricity supply) risks are constrained. This is because construction businesses rely on public electricity supply businesses to provide reliable power and because electricity distribution businesses are natural monopolies (with monopoly power). Market and regulatory/government failures affecting the electricity sector are discussed in the electricity chapter.

Market and government failures in public health sector	Worker health concerns under heatwave conditions are the dominant contributing factors causing disruption. A more health workforce is less susceptible to heat-related illness. However, the capacity of construction businesses to fully manage these risks by themselves is constrained by several market and government failures affecting public health sector (e.g. disclosure/accuracy of food nutrition information). Addressing barriers impacting public health generally will help address vulnerabilities for the construction sector.
ii.	**Policy and regulatory barriers**
Regulatory barriers	Occupational health and safety regulations influence the labour productivity of this sector. Many of these regulations are imposed on the sector; yet, whether these regulations are fully 'efficient' is not clear. The sector may benefit from exploring whether these regulations can be improved.

10.8 Concluding remarks

The vulnerability of the construction sector is currently very high.

To reduce vulnerability, adaptation policy effort should focus on reducing barriers constraining constructions businesses capacity to autonomously manage these risks. Only very limited research on barriers affecting the construction sector have been undertaking as part of this analysis. A more comprehensive and in-depth assessment of barriers is needed.

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11 Manufacturing

11.1 Context

Manufacturers are responsible for producing a diverse range of products, including: processed food, chemicals, furniture, metals etc. (Australian Government 2017). Manufacturing is Victoria's fourth largest industry for employment, totalling 7.8% of the State's working population (ABS 2017) or approximately 280,000 people (Victorian Government 2017). As a snapshot, the sector contributed $27.7 billion to the State's economy in 2016-17 and was responsible for $17.9 billion worth of goods exports in the same financial year (ABS 2017).

11.2 Nature of expected impacts

Heatwaves may impact the manufacturing sector in several different ways. The damages and losses are likely to be related to: direct physical damages on machinery and equipment, reduced labour productivity, electricity service disruptions or disruptions to transport networks.

For manufacturing the direct damages to the sector during periods of extreme heat are likely to be confined to machinery and equipment (particularly electrical equipment). The high ambient temperatures increase the likelihood of machinery and equipment overheating, leading to a reduction in output. In many cases, equipment used within the manufacturing sector will have maximum safe operating temperatures above which the assets either automatically reduce output or shut off to guard against damage. As such, along with possible asset damage, impacts may be experienced within the sector due to a reduction in production associated with equipment damage.

Heatwaves affect the health and productivity of workers (Zander et al. 2015). These impacts may be further amplified by temporary unavailability or shortages of labour due to occupational health and safety requirements or via other instructing guidelines (e.g. WorkSafe Vic 2012) or policies.

The manufacturing sector is also indirectly impacted by heatwave events through electricity service disruptions and peak demand electricity prices. Electricity disruptions affect operation of machinery and equipment critical to production that is powered by electricity, causing production to slow or halt in affected areas. Power disruptions might also affect function of other electrified assets that are not directly part of the manufacturing process (e.g. roller doors within the manufacturing facility) but influence output. Heatwaves can further lead to an increase in peak demand electricity prices, contributing to higher costs of production (ISR 2010).

In addition, disruptions to the transport network associated with heatwave events may impact the delivery of materials used for manufacturing or the ability to freight finished products.

Damages and losses expected in the manufacturing sector are highlighted within Table 24.

Table 24 Types of damages and losses expected in the manufacturing sector

Damages	Losses
Damage to select machinery and equipment (particularly electrical)	Lower production
	Higher costs of production

Note, this analysis assesses disruptions to production only. It does not assess the higher costs of production as the effect of heatwaves on peak demand electricity prices was not modelled as part of this analysis.

11.3 Sensitivity

Manufacturing can be described as having a "moderate sensitivity" to heatwave hazards. The degree of loss is directly related to intensity and duration of the heatwave event – with a greater intensity and duration leading to impacts of greater magnitude.

Direct damage to assets used in manufacturing is not a key element of sensitivity for this sector; instead, sensitivity is driven by diminished labour productivity and power outages.

At lower heatwave intensities (< 60 EHF) losses are primarily driven by diminished labour productivity. Labour productivity affects are closely linked to the physicality of a given job, and this includes staff who work predominantly indoors (Zander et al. 2015). As such, it is expected that as heatwave intensity increases labour productivity will decrease at an increasing rate.[75]

At higher heatwave intensities, electricity service disruptions also contribute to losses to a minor degree in line with the localised areas that experience outages.[76] Road network disruptions from heatwaves are not considered to materially influence manufacturing as these disruptions are minor and most manufacturing freight is not highly time-sensitive.

The sensitivity function for the sector is shown in Figure 21. The function has been developed by combining the labour productivity impacts based on Zander et al. (2015) with the effects of electricity outages estimated in the electricity sector chapter. [77]

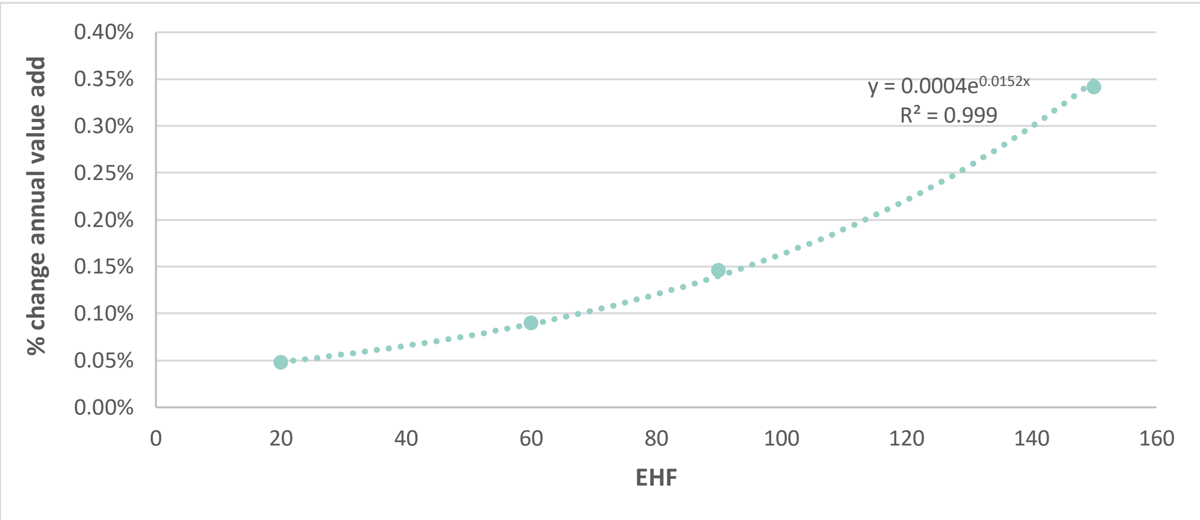

Figure 21 Sensitivity function for the manufacturing sector

[75] For this assessment it was assumed that manufacturing was undertaken indoors and therefore productivity losses associated with mandated/regulated staff breaks triggered by excessive heat (per CFMEU 2015, ACTU 1998 as examples) do no operate.
[76] For analysis it has been assumed that production stops in affected areas for as long as there is a power outage.
[77] The effects of labour productivity reductions on production (% change to production) during heatwave events was derived from the findings presented in Zander et al. (2015) – a study that collected self-assessed data from participants for the 12 months before either May or October 2014. These findings were extrapolated - assuming an exponential function shape like labour productivity loss estimated in the construction sector - to approximate the effect for different heatwave events/EHF values. It was assumed that most manufacturing plants are not air-conditioned, and so labour productivity impacts would translate to a complete loss of production (i.e. capital productivity is also zero during these times as there are no workers to oversee/operate them). To the extent that that this is incorrect for some manufacturing plants, the results are likely to overstate impacts.

11.4 Extent of potential impacts

The magnitude of losses for the manufacturing sector are 'medium'. For severe and extreme levels of heatwave intensity losses are in the order of $14 million and $29 million respectively, increasing significantly to approximately $83 million for the very extreme events. See Table 25 for a summary of results.

Table 25 Quantification of loss in the manufacturing sector

Sub-sector	Losses ($Millions)		
	'Severe' heatwave event	'Extreme' heatwave event	'Very extreme' heatwave event
Manufacturing	14.31	29.11	83.23
Total	14.31	29.11	83.23

These results should be treated with a degree of caution given the lack of directly observed impact data for this sector from heatwave events. Further confidence in the results can be achieved by monitoring effects from heatwave events, refining the analysis by splitting the sector into sub-sectors, and undertaking a more in-depth examination into the realities of lost labour productivity in the manufacturing sector.

> "Manufacturing workers in non-air-conditioned indoor workplaces are also at risk of heat-related illness despite little or no direct sunlight radiation. The levels of heat stress can be very high in workplaces surrounding hot machines, furnaces, ovens, and molten metal. Even in winter, the temperatures near furnaces in a steel plant have ranged from 35.5 to 46.5°C when the outdoor temperature was only 14 – 18 degrees Celsius). Increased hot days due to climate change may worsen the extent of heat stress for individuals working around heat generating sources." (Xiang et al. 2014)

Box 6. Concerns for manufacturing workers on the factory floor

11.5 Probability-weighted extent of impacts

The probability-weighted magnitude of losses for the manufacturing sector is summarised in Table 26. This table also includes impacts for future time periods (2030 and 2050) - assuming vulnerabilities remain at their current levels.

Table 26 Annual expected impact for manufacturing sector for each heatwave category

Heatwave intensity	2018 Annual 'expected' impact ($M)	2030 (RCP 8.5) Annual 'expected' impact ($M)	2050 (RCP 4.5) Annual 'expected' impact ($M)	2050 (RCP 8.5) Annual 'expected' impact ($M)
'Severe'	7.16	14.36	15.97	18.94
'Extreme'	1.16	2.27	2.48	3.33
'Very extreme'	0.76	2.02	1.99	3.28

As can be seen, it is the severe level heatwave events that present the greatest risks for the manufacturing sector. These level events occur regularly now and are expected to become even more common in the medium to long term future under the effects of climate change.

11.6 Distribution of impacts

The figure below illustrates the estimated impacts across the different Regional Partnerships in Victoria. The results indicate that manufacturing in Melbourne suffers the greatest total loss (at approximately $11.2M for 'severe' heatwaves), as expected given that most of the State's manufacturing activity occurs within this zone. The Barwon regional partnership zone is the next biggest contributor (at approximately $575,000 for 'severe' heatwaves) with Loddon Campaspe third (at approximately $504,000 for 'severe' heatwaves). Wimmera Southern Mallee is the smallest total contributor (at approximately $85,000 for 'severe' heatwaves).

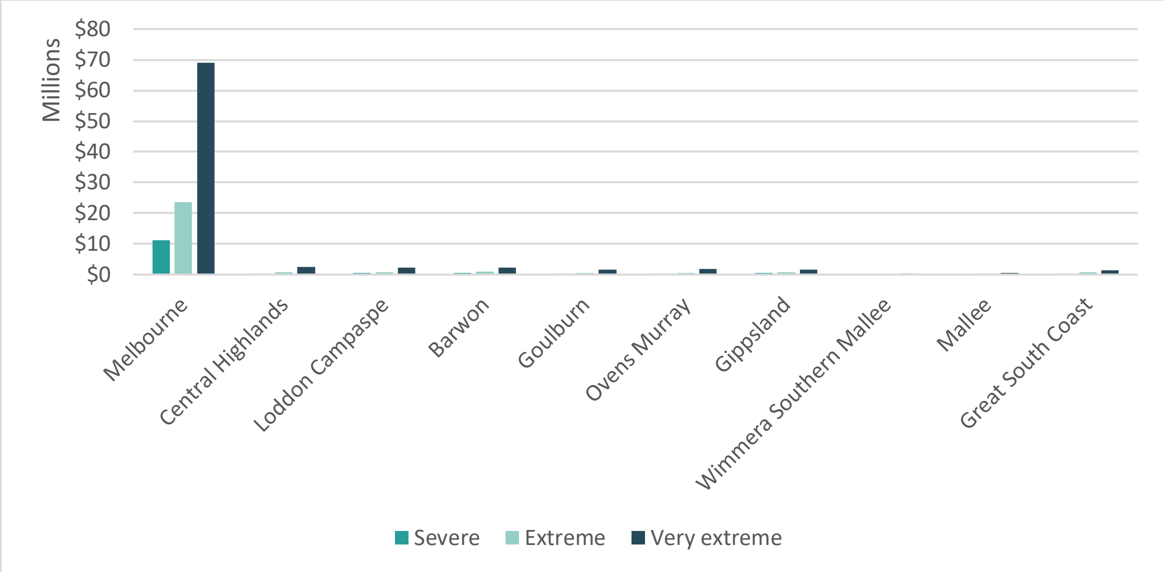

Figure 22 Distribution of manufacturing losses across regional partnership areas, by heatwave intensity level

11.7 Barriers to effective adaptation

There are several barriers and impediments that constrain the manufacturing sector's capacity to autonomously manage heatwave risks. Select barriers that have been identified in this sector are summarised in the table below.

Table 27 Barriers constraining the capacity of the manufacturing sector to adapt to heatwave hazards

i. Market failures	
Information failures	It is likely that a lack of understandable medium-term climate forecasting information – and what this means for manufacturing operations - constrains manufacturing businesses to adapt to heatwave risks. For example, a lack of information and knowledge about how likely 'extreme' heatwave events will be in 10 years time may impede businesses ability to design new manufacturing plants that are 'heatwave smart' (e.g. 'cooler' design buildings, equipment with higher ambient air temperature safety thresholds).
Market and government failures in electricity sector	Electricity outages resulting from heatwave events are a material cause of disruptions to manufacturing; yet, the capacity of many manufacturing sector businesses to fully manage these (heatwave-related electricity supply) risks are constrained. This is because manufacturers rely on public electricity supply businesses to provide reliable power and because electricity distribution businesses are natural monopolies (with monopoly power). Market and regulatory/government failures affecting the electricity sector are discussed in the electricity chapter.

Market and government failures in public health sector	Worker health concerns under heatwave conditions are the dominant contributing factors causing disruption. A more health workforce is less susceptible to heat-related illness. However, the capacity of manufacturing businesses to fully manage these risks by themselves is constrained by several market and government failures affecting public health sector (e.g. disclosure/accuracy of food nutrition information[78]). Addressing barriers impacting public health generally will help address vulnerabilities for the manufacturing sector.
ii.	**Policy and regulatory barriers**
Regulatory barriers	Occupational health and safety regulations influence the labour productivity of this sector. Many of these regulations are imposed on the sector; yet, whether these regulations are fully 'efficient' is not clear – query; do the regulations align with what is optimal for efficient and safe manufacturing production? The sector can benefit from exploring whether these regulations can be improved.

Is lost labour productivity (due to extreme heat) in the manufacturing sector going to exist in the future?

The losses in this sector may be mitigated to some degree by the advancement in technologies to replace jobs currently being undertaken by humans. This vulnerability analysis has shown that loss within this sector is primarily related to diminished labour productivity, which becomes more prevalent as ambient air temperature increases. As technologies advance it is possible that tasks currently being undertaken by humans will be efficiently replaced by machines.

Box 7. The future of lost labour productivity in the manufacturing sector

11.8 Concluding remarks

The vulnerability of the manufacturing sector to heatwave events is medium.

The focus of (heatwave-related) adaptation policy effort in the short – medium term should be on integrating consideration of heatwave risk into mainstream planning and operational processes. This will benefit from addressing (medium-term) climate information barriers and needs.

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[78] Poor nutrition is a major contributor to non-communicable diseases which in turn makes individuals more susceptible to the heatwave related health effects.

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12 Mining

12.1 Context

Victoria's mining sector extracts several different commodities, including; brown coal, gold, mineral sands and base metals (State of Victoria 2017). The value of this production was approximately $3.2 billion in 2015-16, accounting for 0.9% of the State's total (ABS 2017b). The sector employs approximately 9,100 people (ABS 2017a).

12.2 Nature of expected impacts

Heatwaves may impact the mining sector in several ways.

Direct damages to the sector from heatwave hazards are likely to be confined to machinery and equipment. The high ambient temperatures increase the likelihood of machinery and equipment overheating, leading to a reduction in output. In some cases, equipment used within the mining sector will have maximum safe operating temperatures above which the assets either automatically reduce output or shut off to guard against damage.

Heatwaves also affect the health and productivity of mining workers (Leveritt 1998). These impacts may be further amplified by shortages of labour due to occupational health and safety requirements or via other instructing guidelines (e.g. WorkSafe 2012) or union policies (e.g. CFMEU 2015).

In addition, heatwave-related disruptions to the transport network may further impact on the mining sector in some instances, affecting the delivery of input materials/equipment as well pick up of output.

Damages and losses expected in the mining sector are highlighted within Table 28.

Table 28 Types of damages and losses expected in the mining sector

Damages	Losses[79]
Damage to select machinery and equipment (particularly electrical).	Disruptions to mining.

12.3 Sensitivity

The mining sector is considered to have a 'low to moderate' sensitivity to extreme heat.

Losses in this sector are primarily driven by diminished labour productivity. Mining workers are among the most vulnerable population to heat stress as a majority of their work is undertaken outdoors or underground, leaving them highly susceptible to the effects of heatwaves. As such, it is expected that as heatwave intensity increases labour productivity will decrease at an increasing rate. The Victorian Occupational Health and Safety Act (2004) does not specifically mention when work on site should cease due to extreme heat but it does convey a power to WorkCover to make guidelines (s 12). WorkCover provides guidance about working in heat but does not specify when certain actions should be triggered (WorkSafe 2012). However, policies prepared by industry unions exist to provide recommendations to mining operations about working during extreme heat conditions (see CFMEU 2015).

Given the physical nature of their job, mining workers take breaks during periods of high ambient air temperature – a process encouraged by WorkSafe Victoria – to reduce exposure to heat related illness and injury. More specifically, the CFMEU stipulate that work on site should cease and workers should leave the site when the temperature reaches 35 degrees Celsius (CFMEU 2015).[80] The CFMEU policy has widespread

[79] Attributable to asset damage as well as occupational health and safety guidelines, and diminished labour productivity.
[80] Other policies prepared by other unions specify breaks (of variable length given certain temperatures) to ensure that workers' have a chance to rest and cool down (see ACTU 1998 for an example).

application, which significantly affects the composition of the sensitivity function depicted in **Error! Reference source not found.**. Even at lower heatwave intensities the CFMEU 'cease work policy' may operate given that the policy requires the ambient air temperature at that moment to be 35 degrees Celsius or greater compared to the calculation of EHF (which is based on a three-day-averaged daily mean temperature).

Road network disruptions from heatwaves are not expected to materially influence mining as there are likely to be methods to work around transport disruptions via alternative modes of transportation, and because mining inputs/outputs are generally not time-sensitive.[81]

The sensitivity function is shown in Figure 23. This function has been developed by approximating labour productivity impacts based on the CFEMU (2015) cease work policies.[82]

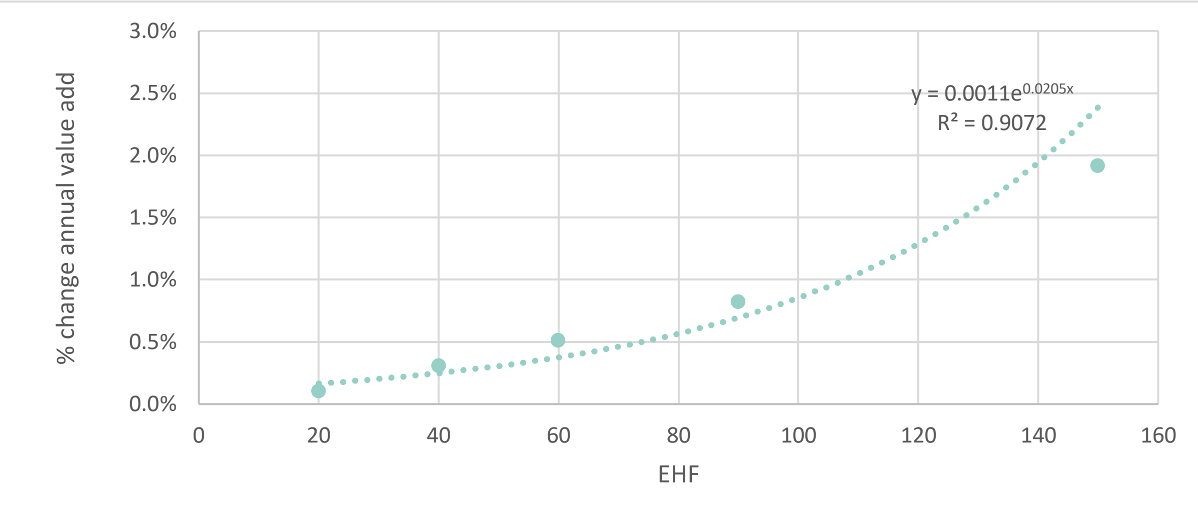

Figure 23 Sensitivity function for the mining sector

12.4 Extent of potential impacts

The magnitude of losses for the mining sector are summarised in Table 29. For severe and extreme intensity levels impacts are in the order of $6 million and $15 million respectively, increase significantly to approximately $62 million for the very extreme events.

Table 29 Quantification of loss in the mining sector

Sub-sector	Losses ($Millions)		
	'Severe' heatwave event	'Extreme' heatwave event	'Very extreme' heatwave event
Mining	5.96	15.16	62.10
Total	5.96	15.16	62.10

These results should be treated with a degree of caution given the lack of directly observed impact data for this sector from heatwave events. Further confidence in the results can be achieved by monitoring effects

[81] Note, even with generous assumptions, the transport sector does not appreciably affect the sensitivity function.
[82] The effects of labour productivity reductions on mining (% change to mining) during heatwave events was derived from the CFMEU (2015) policies. The function was developed by approximating the duration for which the policy would be triggered and for how long, assuming an exponential function shape. An analysis of the relationship between EHF intensity and ambient air temperature had to be undertaken to inform this approach.

from heatwave events and undertaking a more in-depth examination into the realities of lost labour productivity in the mining sector.

> "Heat stress is the sum of all the internal and external heat factors which cause the body to become fatigued and distressed. In extremely hot environments there is a significant decrease in productivity and a high rate of accidents as well as the risk of workers suffering heat disorders. Internal factors that determine the level of heat stress on the body include core body temperature, acclimatisation, natural heat tolerance and metabolic heat generated by the workload. External factors include ambient air temperature, radiant heat, air velocity and humidity (Lahey 1984)." (Leveritt 1998)

Box 8. **What is heat stress?**

12.5 Probability-weighted extent of impacts

The probability-weighted magnitude of losses for the mining sector is summarised in Table 30. This table also includes impacts for future time periods (2030 and 2050) - assuming vulnerabilities remain at their current levels.

Table 30 Annual expected impact for mining sector for each heatwave category

Heatwave intensity	2018 Annual 'expected' impact ($M)	2030 (RCP 8.5) Annual 'expected' impact ($M)	2050 (RCP 4.5) Annual 'expected' impact ($M)	2050 (RCP 8.5) Annual 'expected' impact ($M)
'Severe'	2.98	5.98	6.65	7.88
'Extreme'	0.61	1.18	1.29	1.73
'Very extreme'	0.56	1.51	1.49	2.45

As can be seen, it is the severe level heatwave events that present the greatest risks for the mining sector. These level events occur regularly now and are expected to become even more common in the medium to long term future under the effects of climate change.

12.6 Distribution of impacts

The figure below illustrates the estimated impacts across the different Regional Partnerships in Victoria. The results indicate that mining in Melbourne suffers the greatest total loss (at approximately $3.2M for 'severe' heatwaves). The Gippsland regional partnership zone is the next biggest contributor (at approximately $890k for 'severe' heatwaves) with Loddon Campaspe third (at approximately $592k for 'severe' heatwaves). Ovens Murray is the smallest total contributor (at approximately $96k for 'severe' heatwaves).

The distribution of mining losses across regional partnership zones are a function of how value add was mapped for this analysis. The results for 'Melbourne' are likely to be overstated due to professional services for this sector being in Melbourne - compared to actual mining operations that are more exposed to heatwave events. Labour productivity effects from heatwave events are at least 40 per cent higher for labourers and outside workers compared to office workers (Zander et al. 2015).

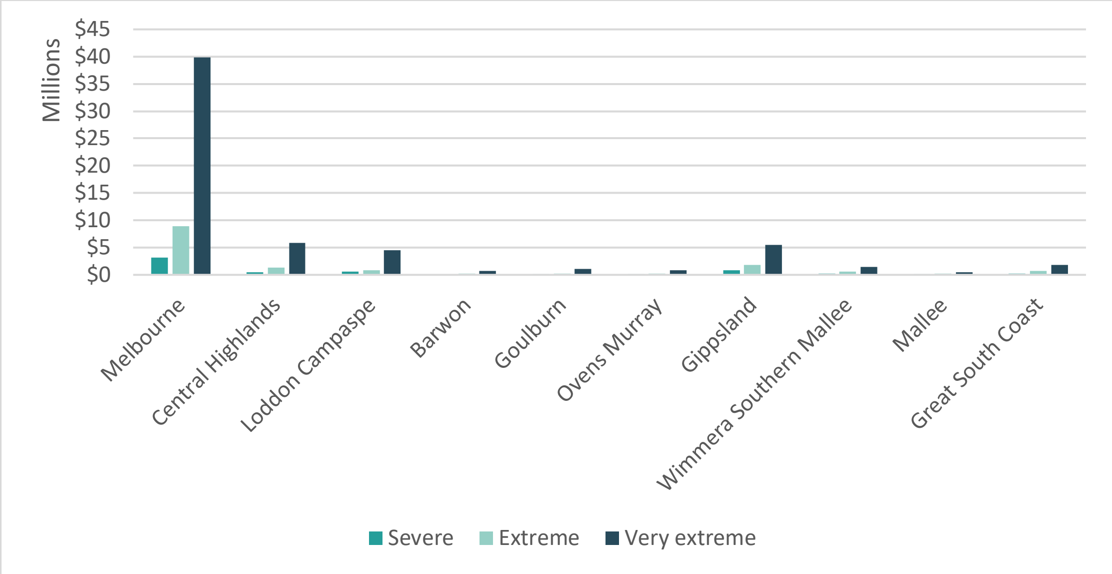

Figure 24 Distribution of mining losses across regional partnership areas, by heatwave intensity level

12.7 Barriers to effective adaptation

There are several barriers and impediments that constrain the mining sector's capacity to autonomously manage heatwave risks. Select barriers that have been identified in this sector are summarised in Table 31 below.

Table 31 Barriers constraining the capacity of the mining sector to adapt to heatwave hazards

i.	Market failures
Information failures	It is likely that a lack of understandable medium-term climate forecasting information – and what this means for mining operations - constrains mining businesses to adapt to heatwave risks. For example, a lack of information and knowledge about how likely 'extreme' heatwave events will be in 10 years time may impede businesses ability to design new processes that are 'heatwave smart'.
Market and government failures in public health sector	Worker health concerns under heatwave conditions are the dominant contributing factors causing disruption. A more health workforce is less susceptible to heat-related illness. However, the capacity of mining businesses to fully manage these risks by themselves is constrained by several market and government failures affecting public health sector (e.g. disclosure/accuracy of food nutrition information). Addressing barriers impacting public health generally will help address vulnerabilities for the mining sector.
ii.	**Policy and regulatory barriers**
Regulatory barriers	Occupational health and safety regulations influence the labour productivity of this sector. Many of these regulations are imposed on the sector; yet, whether these regulations are fully 'efficient' is not clear – query; do the regulations align with what is optimal for efficient and safe mining? The sector can benefit from exploring whether these regulations can be improved.

	“Proper application of engineering protocols and work practice controls will have a direct impact on the health and safety of workers and increased productivity.” (Anderson and De Souza 2017)

12.8 Concluding remarks

The vulnerability of the mining sector to heatwave events is low.

The focus of (heatwave-related) adaptation policy effort in the short – medium term should be on integrating consideration of heatwave risk into mainstream planning and operational processes. This will benefit from addressing (medium-term) climate information barriers and needs.

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13 Tourism

13.1 Context

Tourism is made up of a share of several different sectors, including: accommodation (14%), food (29%), retail trade (17%) and education (10%) (TRA 2017b).[83] Tourism totals 27.4% of the workforce within Victoria and contributed (either directly[84] or indirectly[85]) $20.8 billion to Victoria's gross value add in 2015-16 (TRA 2017b).

13.2 Nature of expected impacts

Heatwaves are likely to impact the tourism sector in a variety of different ways. These impacts occur through reduced labour productivity, electricity service disruptions and disruptions to transport networks. Importantly, they are also likely to occur through degradation of environmental assets which provide recreational services important for tourism.

Heatwaves affect the health and productivity of the workers even if those workers are likely to spend a significant proportion of their working day indoors (Zander et al. 2015). These impacts may be further amplified by temporary unavailability or shortages of labour due to occupational health and safety requirements or via other instructing guidelines (e.g. WorkSafe 2012) or policies.

The tourism sector is also impacted by heatwave events through electricity service disruptions and peak demand electricity prices. Electricity disruptions affect the operation of critical assets required for service delivery spanning all sub-sectors (i.e. hotels under accommodation, restaurants under food, shopping centres under retail trade etc.). These disruptions are likely to inhibit a tourist's experience (e.g. by inconveniencing a service), most likely resulting in a decline in spending in affected areas due to an inability for the service to run as normal.

Further, disruptions to the transport network associated with heatwave events can potentially also result in loss for the tourism sector (e.g. inability to deliver ingredients for food outlets, prevent a guided tour to proceed etc.).

In addition, damage to the condition of ecosystem assets (e.g. State and National Parks) could also impact the tourism sector by altering the quality of the recreational experiences/services provided by these assets and in turn visitor numbers.

Damages and losses expected in the tourism sector are highlighted within Table 32.

Table 32 Types of damages and losses expected in the tourism sector

Damages	Losses
Damage to ecosystem assets	Disruptions and reductions in service delivery. [86]
	Higher cost of service delivery. [87]
	Loss of recreation services

This analysis assesses disruptions and reductions in service delivery pertaining to labour productivity, electricity disruptions, and transport disruptions only.

[83] Percentages refer to employment per sub-sector.
[84] Money spent directly in the tourism industry – without a tourism industry in Victoria this money wouldn't be generated, or these people wouldn't be employed (TRA 2017a).
[85] The flow-on effect of the tourism industry. For every dollar spent in the tourism industry, additional monies spent elsewhere in the economy.
[86] Attributable to electricity service disruptions, occupational health and safety guidelines, and diminished labour productivity.
[87] Attributable to an increase in peak demand electricity prices, occupational health and safety guidelines, and diminished labour productivity.

It does not assess potential losses relating to potential degradation of ecosystem assets as readily available information precludes this analysis (refere environment sector chapter). Nor does it assess higher costs pertaining to peak demand electricity prices.[88]

13.3 Sensitivity

At lower heatwave intensities (< 60 EHF) losses include diminished labour productivity. Labour productivity affects are closely linked to the physicality of a given job, and this includes staff who work predominantly indoors (Zander et al. 2015). As such, it is expected that as heatwave intensity increases labour productivity will decrease at an increasing rate.

At higher heatwave intensities, electricity service disruptions may also contribute to losses to a minor degree in line with the localised areas that experience outages.[89]

Road network disruptions from heatwaves are not considered to materially influence tourism as these disruptions are minor and there are normally alternative transport routes/options that can be taken.

Potential damages to ecosystems from heatwaves could cause significant – and possibly long-term or permanent - losses for tourism. However, as discussed in the environment sector chapter, there are considerable uncertainties with the information currently available on these damages, which precludes quantitative analysis.

The sensitivity function for the sector is shown in Figure 25. The function has been developed by combining the effects of electricity outages estimated in the electricity sector chapter with labour productivity impacts based on Zander et al. (2015).[90]

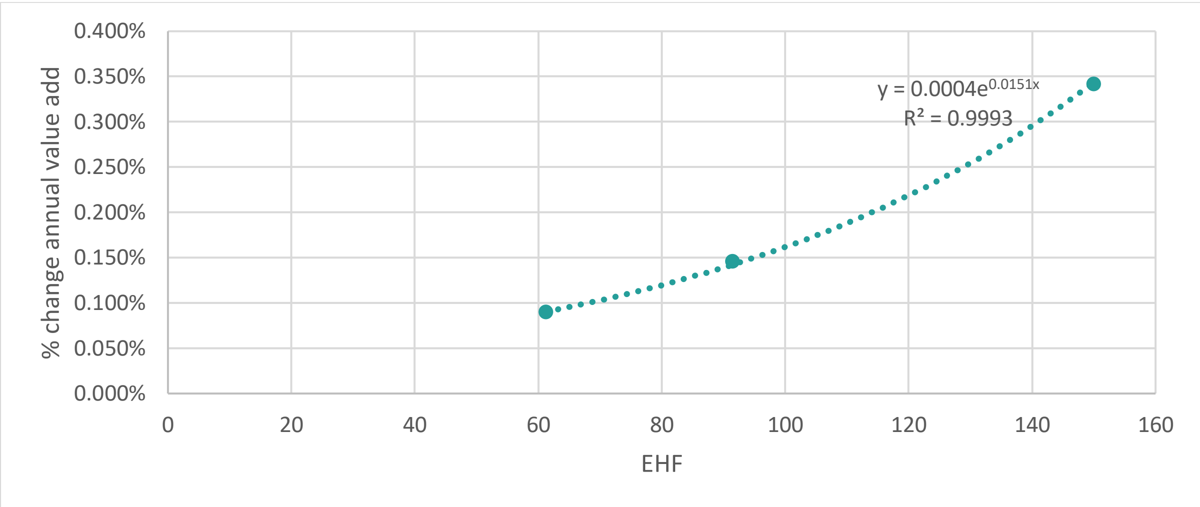

Figure 25 Sensitivity function for tourism

[88] Because these effects - a very complex undertaking - were not modelled as part of the analysis.
[89] For analysis it has been assumed that production stops in affected areas for as long as there is a power outage.
[90] The effects of labour productivity reductions on goods/service delivery (% change to goods/service delivery) during heatwave events was derived from the findings presented in Zander et al. (2015) – a study that collected self-assessed data from participants for the 12 months before either May or October 2014. These findings were extrapolated - assuming an exponential function shape like labour productivity loss estimated in the construction sector - to approximate the effect for different heatwave events/EHF values. It was assumed that most tourism operations are either outdoors do not operate in air-conditioned environments and so labour productivity impacts would translate to a complete loss of production (i.e. capital productivity is also zero during these times as there are no workers to oversee/operate them). To the extent that that this is incorrect for some tourism activities, the results are expected to overstate impacts.

13.4 Extent of potential impacts

The magnitude of quantified losses for the tourism sector are 'low' with severe and extreme heatwaves causing impacts of around $2 million and $4 million respectively and increasing to approximately $11 million for the very extreme events. See Table 33 for a summary of results.

Table 33 Quantification of loss in the tourism sector

Sub-sector	Losses ($Millions)		
	'Severe' heatwave event	'Extreme' heatwave event	'Very extreme' heatwave event
Tourism	1.84	3.79	10.97
Total	1.84	3,79	10.9 7

It is highlighted that these results do not account for the (potentially significant and long-term) loss of recreation services associated with potential degradation of ecosystem assets. When these factors are taken into consideration the impacts on the tourism are expected to much higher.

Park-attributable tourism to the Victorian economy is conservatively estimated at around $1 billion Gross Value Added (GVA) per year.

Research undertaken by CSIRO (Dunlop et al. 2016) suggests that the biophysical damage to ecosystem assets and associated losses of ecosystem services expected from (broader) climate change over the relative near term is very substantial. By 2030, the combined effects of climate change are expected to cause around half the species within existing ecosystems to change. And by 2070, species composition - on average - is expected to be more different than it is like the current situation. This is likely to have a dramatic affect to many ecosystem services into the future, including ecotourism. Parks receive between 30 and 51 million visits every year, emphasising that the tourism sector is firmly connected to the vulnerability and evolution of the environment.

Box 9. The link between ecosystem asset health and tourism

13.5 Probability-weighted extent of impacts

The probability-weighted magnitude of losses for the tourism sector is summarised in Table 34. This table also includes impacts for future time periods (2030 and 2050) - assuming vulnerabilities remain at their current levels.

Table 34 Annual expected impact for tourism sector for each heatwave category

Heatwave intensity	2018 Annual 'expected' impact ($M)	2030 (RCP 8.5) Annual 'expected' impact ($M)	2050 (RCP 4.5) Annual 'expected' impact ($M)	2050 (RCP 8.5) Annual 'expected' impact ($M)
'Severe'	0.92	1.85	2.06	2.44
'Extreme'	0.15	0.30	0.32	0.43
'Very extreme'	0.10	0.27	0.26	0.43

As can be seen, it is the severe level heatwave events that present the greatest risks for the tourism sector. These level events occur regularly now and are expected to become even more common in the medium to long term future under the effects of climate change.

13.6 Distribution of impacts

Figure 26 illustrates the estimated impacts across the different Regional Partnerships in Victoria. The results indicate that tourism in Melbourne suffers the greatest total loss (at approximately $1.42M for 'severe' heatwaves).[91] The Barwon regional partnership zone is the next biggest contributor (at approximately $91,000 for 'severe' heatwaves) with Gippsland third (at approximately $71,000 for 'severe' heatwaves) – a known popular destination for tourist. Wimmera Southern Mallee is the smallest total contributor (at approximately $15,000 for 'severe' heatwaves).

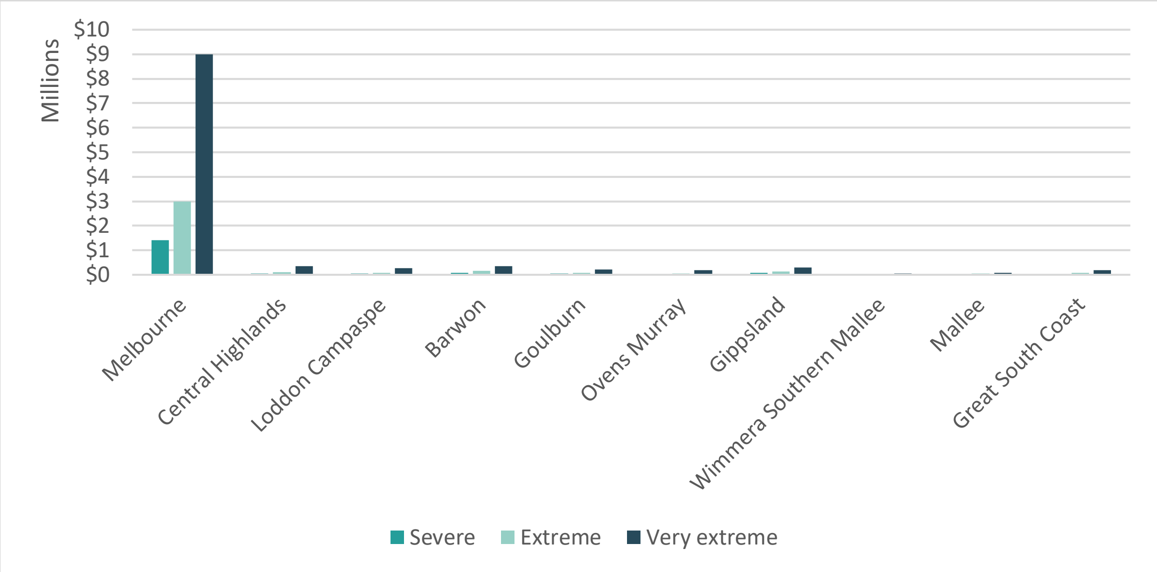

Figure 26 Distribution of tourism losses across regional partnership areas, by heatwave intensity level

It is emphasised again these results do not account for loss of recreational ecosystem services. The distribution of impacts is likely to change when these effects are considered, with regional areas showing much greater absolute impacts.

13.7 Barriers to effective adaptation

There are several barriers and impediments that constrain the tourism sectors capacity to autonomously manage heatwave risks. Select barriers that have been identified in this sector are summarised in Table 35 below.

Table 35 Barriers constraining the capacity of the tourism sector to adapt to heatwave hazards

i.	Market failures
Information failures	It is likely that a lack of understandable medium-term climate forecasting information – and what this means for tourism operations - constrains tourism businesses to adapt to heatwave risks. For example, a lack of information and knowledge about how likely 'severe' heatwave events will be in 10 years time may impede businesses ability to plan new products (e.g. mix of attractions that are not all susceptible to heatwave events).

[91] The high value for the Melbourne Regional Partnership area is slightly distorted given the demarcation of the regional partnership. The Melbourne Regional Partnership zone covers the Melbourne metropolitan area as well as some rural and/or high value tourism areas such as the Yarra Ranges.

Market and government failures in electricity sector	Electricity outages are a material cause of tourism service disruptions during heatwave events. However, the capacity of many tourism sector business to fully manage these (heatwave-related electricity supply) risks is constrained because they rely on public electricity supply businesses to provide these services and because electricity distribution businesses are natural monopolies (with monopoly power). Market and regulatory/government failures affecting the electricity sector are discussed in the electricity chapter.
Market and government failures in public health sector	Worker heat-related incidences are a contributing factor to the disruption of providing tourism services. However, the capacity of the businesses to fully manage these risks by themselves is constrained by several market and government failures affecting public health sector (e.g. inadequate public communication and education on heatwave risks – particularly within the workplace). Market and government failures affecting the public health sector are discussed in the health chapter.
Market and government failures in the environment sector	The quality of recreation services important for tourism may be negatively impacted by heatwave events. Market and government failures affecting the environment sector are discussed in the environment chapter.
ii. **Policy and regulatory barriers**	
Regulatory barriers	Occupational health and safety regulations influence the labour productivity of this sector. Many of these regulations are imposed on the sector yet whether these regulations are fully 'efficient' is not clear. The sector can benefit from exploring whether these regulations can be improved.

13.8 Concluding remarks

The vulnerability of the tourism sector to heatwave events is not clear as the potential (biophysical) impacts on ecosystem assets (an important contributor of recreational services to the tourism sector) are currently not well understood. Given ecosystem service losses could be substantial and long-term, vulnerability of the tourism sector could potentially be high.

The focus of (heatwave-related) adaptation policy effort in the short – medium term should be on integrating consideration of heatwave risk into mainstream planning and operational processes.

The other key focus should be on better managing ecosystem assets for heatwave (and other climate-related risks). The tourism sector has a key role in inputting to these management planning decisions.

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14 Health

14.1 Context

Victoria's health system covers all the services whose primary purpose is to promote, restore and/or maintain health'. These include, but are not limited to, public health and preventive services in the community, primary health care[92], emergency health services, hospital-based treatment in public and private hospitals, and rehabilitation and palliative care.

Health services in Victoria are provided by a variety of organisations and health professionals, including medical practitioners, nurses, allied and other health professionals, hospitals, clinics, pharmacies, and government and non-government agencies. Public hospitals are operated by the Victoria Government (and funded by the both the Victoria and Australian Governments). Private hospitals are owned and operated by the private sector but licensed and regulated by governments. Local governments also play a significant role in health. In addition to providing community-based health and home care services, Local Governments provide health promotion activities such as promoting heatwave awareness and safety (AIHW 2016).

Expenditure on health is traditionally analysed in terms of recurrent expenditure and capital expenditure. Recurrent expenditure can generally be thought of as goods and services consumed within a year. It includes expenditure on health goods (such as medications and health aids and appliances), health services (such as hospital, dental and medical services), public health activities, and other activities that support health systems (such as research and administration) (AIHW 2017). In 2015-16, recurrent expenditure on health in Victoria was $38,858 million (AIHW 2017). Of this, 41 per cent ($15,786 million) was spent on hospital services and 2 per cent ($914 million) was on patient transport services. Over the period 2005-06 to 2015-16, health expenditure per person in Victoria has increased by 2.6% per annum (AIHW 2017).

14.2 Nature of expected impacts

Heat-related illness can range from mild conditions, such as a rash or cramps, through to heat exhaustion, and finally to potentially fatal conditions such as heat stroke.

Anyone can be affected by heatwaves, including the healthy and the physically active (CCA 2016). However, population segments most often and most significantly impacted tend to be the elderly and very young, persons with existing chronic health conditions, low income households, and persons that are socially isolated (Coates et al 2014).

When heatwave events occur and incidences of illness (morbidity) and death (mortality) increase, the demands on public health services also increases. Ambulance services and Emergency Department (ED) services are the most affected with a proportion of ED presentations further admitted to hospital after their ED care (CCA 2016). Also, demands on community health services are reported to increase. This includes nursing homes and medical centres as well as mental health services and domestic violence services (Hansen et al 2008).[93]

Increased incidence of illness and death further translates to a loss of economic production. This occurs through a reduction in available labour for the period it takes for individuals to recuperate and, if workers incur a longer-term disability, performing less efficiently. Sub-clinical (heat-related) health effects also impact on labour productivity. Sub-clinical health effects manifest as higher levels of absenteeism or performing less efficiently (Zander et al 2015).

[92] Broadly encompasses care that is not related to a hospital visit. It includes a range of activities, such as health promotion, prevention, early intervention, treatment of acute conditions, and management of chronic conditions.

[93] Community health services can be further affected by heatwaves through power outages. Unlike hospitals, community health facilities generally are not safeguarded by backup energy supplies (Climate Council, 2016, p17).

The nature of heatwave impacts for the health sector is summarised in Table 36 below.

Table 36 Types of damages and losses in the health sector

Damages	Losses
Illness and death	Increase health service costs to treat illness (and death)
	Labour productivity losses

Losses that are quantified in this (health) sector analysis are increased health service costs to treat illness and death. Losses pertaining to reduced labour productivity are (partially) quantified in the productive sector chapters.

The value of life (lost) is not quantified in the analysis[94].

14.3 Sensitivity

Select components of the health sector (Ambulance, ED, Community Health) are “highly sensitive” to heatwave hazards.

At lower intensity heatwave levels, population segments most susceptible are triggered. Older people are vulnerable as they are more likely to have health conditions (and take associated medications) that can reduce their ability to regulate body temperature and increase their susceptibility to extreme heat (Kovats and Hajat 2008). These conditions include: high blood pressure and cardiovascular disease; diabetes; lung disease; overweight and obesity; lymphoedema; Parkinson’s disease; fibromyalgia; post-polio syndrome/poliomyelitis; and motor neurone disease (Kenny et al 2010).

The possible health impacts become more widespread and severe as heatwave intensity increases - with more segments of the population being affected and the potential to cause unexpected deaths.

At higher intensity heatwave levels, impacts are further exacerbated by disruptions in other sectors of the economy. For example, electricity load shedding triggered by an extreme heat event can limit the ability of individuals to use air-conditioning to stay cool.

In early 2009, Victoria suffered through a long and intense heatwave event that took a significant toll on health. In Melbourne, the EHF index peaked at 122 with temperatures reaching over 43 degrees for three consecutive days. During this event, 374 excess deaths were recorded, ambulance call-outs increased 46 per cent and emergency department (ED) presentations increased 12 per cent (DHS 2009).

Box 10. Case study example of impact in health sector from 2009 heatwave event

The relationship between heatwave intensity (measured in terms of peak EHF) and health sector impacts (in terms of economic value add) is approximated in the ‘sensitivity functions’ below. This has been done for each of the health sub-sectors most affected by heatwave events - namely, (i) Ambulance Services, (ii) Hospital (ED + some admissions), and (iii) Community Health Services.

These functions are based on observed impacts from past heatwave events in Australia – Melbourne & Adelaide 2009, Sydney 2011, and Brisbane 2004. The functions also incorporate a hypothetical heatwave consequences scenario developed as part of the Victorian Preparedness Framework.

[94] As is the practice with the DaLA methodology.

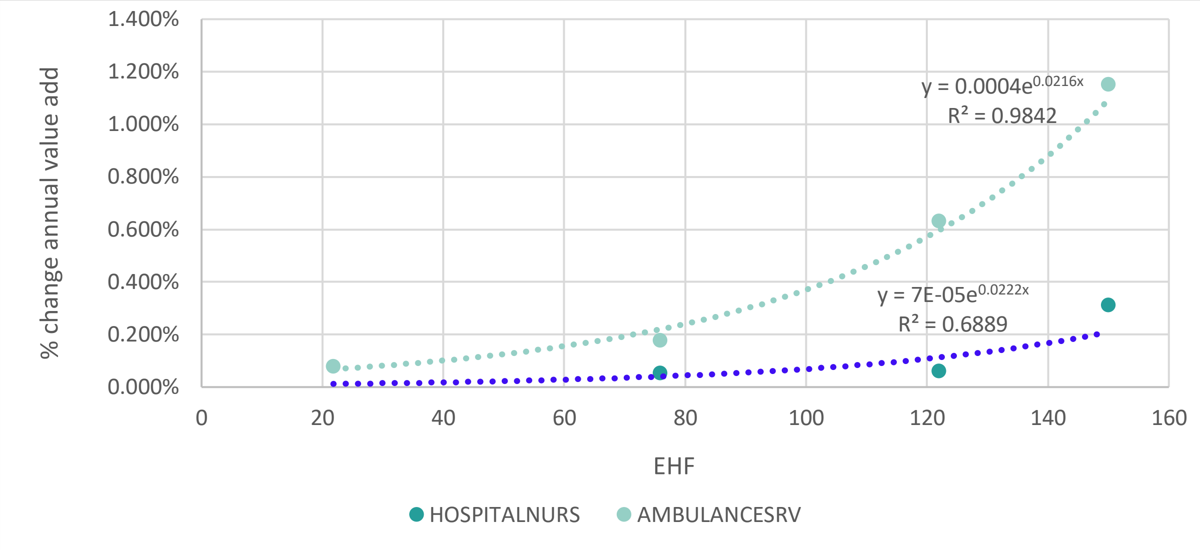

Figure 27 Sensitivity functions for health sector

Data was not able to be obtained to inform the sensitivity function for the community health sub-sector. The analysis of potential impacts for the community health sub-sector is assumed to be the same as for hospitals.

14.4 Extent of potential impacts

The magnitude of losses for the health sector is medium**.** For 'severe' and 'extreme' heatwave events are in the order of $7 million and $20 million respectively, increasing substantially to around $93 million for very extreme events. See Table 37 for a summary of results.

Table 37 Quantification of loss in the health sector

Sub-sector	Losses ($Millions)		
	'Severe' heatwave event	'Extreme' heatwave event	'Very extreme' heatwave event
Ambulance	0.15	0.44	2.13
Hospitals	0.98	2.8 8	13.85
Community Health	5.97	16.81	77.29
Total	7.10	20.13	93.28

A key driver of this result is the community health subsector - which makes up over 80 per cent of total estimated impacts. However, as mentioned in section 14.2 above, little empirical information was available on this aspect and so the sensitivity for this sub-sector was assumed to be the same as for the hospital sub-sector. There is therefore low confidence in this aspect of the results.

In the future, vulnerability of the health sector could further increase in line with an ageing population (CCA 2016) and if important barriers constraining individuals' capacity to adapt are not addressed. Barriers are discussed further in 14.6 below.

14.5 Probability-weighted extent of impacts

The probability-weighted magnitude of losses for the health sector is summarised in Table 38. This table also includes impacts for future time periods (2030 and 2050) - assuming vulnerabilities remain at their current levels.

Table 38 Annual expected impact for health sector for each heatwave category

Heatwave intensity	2018 Annual 'expected' impact ($M)	2030 (RCP 8.5) Annual 'expected' impact ($M)	2050 (RCP 4.5) Annual 'expected' impact ($M)	2050 (RCP 8.5) Annual 'expected' impact ($M)
'Severe'	3.55	7.13	7.93	9.40
'Extreme'	0.81	1.57	1.71	2.30
'Very extreme'	0.85	2.26	2.23	3.67

As can be seen, it is the severe level heatwave events that present the greatest risks for the health sector at this point in time.

Another key insight from the results is also that – if nothing is done to reduce vulnerabilities – heatwave risks substantially increases in the future under the effects of climate change. All category events – severe, extreme, and very extreme – present significant risks for the health sector and will become increasingly important to manage.

14.6 Distribution of impacts

The figure below illustrates the estimated impacts across the different Regional Partnerships in Victoria. The results indicate that health in Greater Melbourne suffers the greatest loss in absolute terms, reflecting the concentration of human populations in this area. Central Highlands and Barwon are next most impacted in absolute terms, but substantially lower than Melbourne.

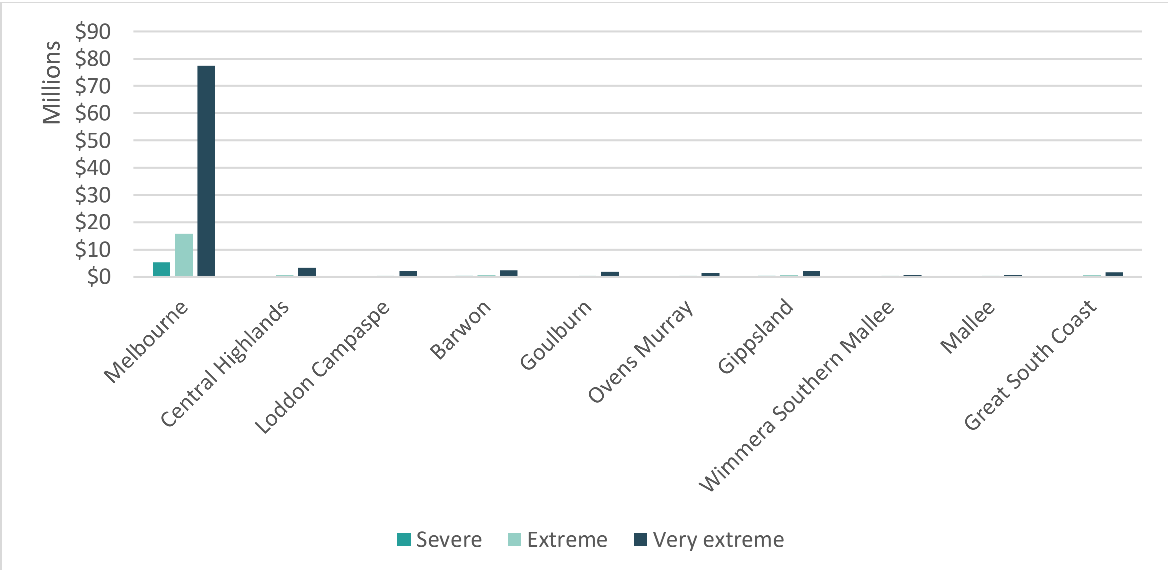

Figure 28 Distribution of health sector losses across regional partnership boundary areas

It is also important to be aware that spatial distribution of health-sector vulnerability/impacts within Regional Partnership Areas is also material for some regions - particularly Greater Melbourne. The economic (value-add) datasets used in this study does not allow for reliable analysis/estimation at the Local Government Area

(LGA) geographical scale. However, Monash University has recently undertaken some work investigating this issue for Greater Melbourne. This research can be found at https://www.monash.edu/news/articles/6639.

14.7 Barriers to effective adaptation

There are a wide range of barriers and impediments that constrain the health sectors capacity to autonomously manage (health related) heatwave risks.

Select barriers that have been identified in this study for the health sector are summarised in Table 39 below. These barriers are generally 'cross-sectoral' in nature and cause constraints at the individual level.

Table 39 Barriers constraining capacity of health sector to adapt to heatwaves

i. Market failures	
Information failures	There is some lack of clarity (across Victorian Government agencies and community groups) about how a heatwave is defined[95], how it is measured (including to account for geographical differences in local climate), and how it is communicated to the public (Scalley et al 2015, CCA 2016). Amongst other things, this appears to affect households understanding of heatwave risks and their ability to effectively respond to heatwave warnings. A survey undertaken by the Bushfire and Natural Hazards Cooperative Research Centre found that 45 per cent of those at risk – including the elderly, ill and very young – did not proactively respond to heatwave warnings as they did not think it necessary or did not know what to do (Gissing and Coates 2018).
Split incentives in residential housing	Differing incentives between owners and occupants of residential dwellings can lead to housing stock that is not (optimally) energy/thermally efficient[96] (VCOSS 2017). This may occur when a prospective occupant imperfectly observes the owner's choice of energy efficiency of the dwelling, reducing the owner's incentive to properly insulate the dwelling or (where appropriate) install air-conditioning units. Poor energy-efficient housing in turn increases occupants' exposure to heat stress and/or increases the costs of managing it (primarily through use of air-conditioning).
'External' benefits of green urban design	Green urban design (e.g. green roofs, vertical gardens) can reduce heat load (from heatwave events) for households as well as for neighbouring households. As such green urban design is potentially an important adaptation response in urban environments (especially where the 'urban heat island' effect is shown to be material). However, because some of the benefits of green design – specifically 'spill over' cooling benefits on neighbouring areas - are not fully captured by (private) providers, there is generally a lack of incentives for individual households/businesses to provide green urban infrastructure – at least not to the level that is socially optimal.
ii. Policy and regulatory barriers	
Cost-reflective electricity pricing policy, and related	Use of air-conditioning is a key response to help many households manage health related risks from heatwaves, with some households (e.g. those

[95] Including how it differs from extreme heat.
[96] For older housing stock not subject to new building code regulations.

public messaging to reduce peak demand in heatwave	including persons with pre-existing health conditions) needing more cooling than others. Cost-reflective pricing policy – which aims to reduce household use of electricity during peak times through pricing mechanisms - is likely to be a barrier for some lower income households to effectively manage their health-related risks from heatwaves[97] (Nicholls et al 2017). Also, public messaging is sometimes used during heatwaves to ask for reductions in electricity use when demand may exceed supply. The Victorian Auditor-General's investigation into the health outcomes of the 2014 heatwave in Victoria reports that elderly Victorians were restricting the use of air conditioners because of advice to conserve power (Victorian Auditor General's Office 2014).
iii. Governance and institutional arrangements	
Inadequate mainstreaming of heatwave risk into Local Government planning	Since the 2009 heatwave, the Department of Human Services has developed a heatwave framework to reduce the impact of extreme heat on public health. The framework includes the *Heatwave Planning Guide for municipal councils.* While most councils and (local government) health services have a heatwave plan, the quality of these plans and the extent to which they are being implemented is variable across local government agencies (VAGO 2014). Discussions with Local Government representatives highlight that, in some cases, heatwave risks have been treated as a separate and standalone issue and not adequately incorporated into Council's key medium-term strategic plan (Council Plan) and related Strategic Resource Plan. As a result, inadequate resources and management attention is allocated to these issues.
iv. Disadvantaged groups (equity)	
Public housing	Low income groups are constrained in their capacity to manage heatwave risks by a lack of available finances. One example of this mentioned already is pertains to the use air-conditioning systems – which can be very expensive to operate at peak demand electricity prices. One dimension of social disadvantage that warrants special attention for heatwaves is housing, and public housing specifically. The majority of Australia's existing housing stock is 20 years of age or older and most of this stock has been built with little consideration of intense heatwave events and climate change (Barnet et al 2013). Disadvantaged populations are more likely to reside in this older, less heatwave-resilient housing stock, and have fewer resources to invest in related adaptation (Barnet et al 2013).

14.8 Concluding remarks

The vulnerability of the health sector to heatwave events is currently medium. Moreover, if nothing is done to reduce vulnerabilities – corresponding risks are expected to substantially increase in the future under the effects of climate change.

[97] In particular: The elderly, very young, and chronically ill who are particularly reliant on cooling to maintain their health, and so are at risk of negative impacts from heat – especially those who live in poor quality housing and have limited options to seek cool spaces beyond their own home. Households who need to use air conditioning during peak times and may experience greater difficulties paying electricity bills. Households who respond by limiting their air conditioning use and may have negative health outcomes.

The focus of (health-related) adaptation policy effort in the short-medium term should be on:

- Undertaking further research to understand the nature and extent of (heatwave) impacts on the community health sub-sector. There is a currently a lack of empirical information pertaining to this important sub-sector.

- Addressing barriers constraining the capacity of the individuals and the health system generally to efficiently manage changing heatwave risks. This includes barriers which are cross-sectoral in nature and which thus require cross-sectoral collaboration.

- Strengthening integration of heatwave risk considerations into mainstream planning and operational processes. This is especially important at the Local Government level where heatwave risks have sometimes been treated as a separate and standalone item and not adequately incorporated into Council's key medium-term strategic plan (Council Plan) and related Strategic Resource Plan.

Public health effects also contribute to vulnerability in other sectors through lower labour productivity.

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15 Environment (cross-cutting sector)

15.1 Context

Ecosystem assets[98] are a key component of the Victorian economy. If well managed, ecosystems provide a wide range of services (referred to as ecosystem services[99]) important for many infrastructure, productive and social sectors.

The most extensive land-ecosystem assets in Victoria – defined in terms of major vegetation groups – are Eucalypt Open Forests (4,976,481 Ha, 47 per cent of total land-ecosystem asset area), Eucalypt Woodlands (2,459,569 Ha, 23 per cent of total land-ecosystem asset area), and Mallee Woodlands and Shrubs (1,577,654 Ha, 15 per cent of total land-ecosystem asset area) (DSE 2013). There are also other smaller scale ecosystems that provide proportionately higher levels of ecosystem services. These include Casuarina Forests and Woodlands (190,513 Ha, 1.82 per cent of total land-ecosystem asset area) and Tussock Grasslands (139,989 Ha, 1.33 per cent of total land-ecosystem asset area) (DSE 2013).

A large proportion of land-ecosystem assets in Victoria (approximately 70 per cent) are managed as State and National Parks, Conservation Areas, Forest Reserves, and Natural Water Reserves (DSE 2013).[100] Ecosystem assets managed by Parks provide a wide range of ecosystem services. These services and their contribution to the Victorian economy include (PV and DELWP 2015):

- *Provisioning services – clean water and honey.* Parks provide around 3,400 gigalitres of water (16% of the State total) per annum– worth around $244 million. This water is particularly significant for the communities of eastern Victoria (Alpine, Lake Eildon National Parks), western Victoria (Grampians National Park) and Greater Melbourne (Yarra Ranges National Park). Beehives in parks and reserves are estimated to produce about 1,200 to 1,600 tonnes of honey products per annum, which is worth $3.4-$4.6 million per annum.

- *Regulating services – water filtration, pollination, coastal protection, flood protection, and carbon sequestration.* Parks provide valuable water filtration services, valued at around $88 million per annum. Parks also provide important pollination services ($123-167 million per annum), coastal protection (valued at $24-56 million per annum), flood protection ($46 million per annum), carbon sequestration ($1-5 million per annum).

- *Cultural services – recreation, amenity, cultural heritage connection and health*. Parks receive between 30 and 51 million visits every year, with almost 17 million visitor nights being from tourists. Park-attributable tourism to the Victorian economy is conservatively estimated at around $1 billion Gross Value Added (GVA) per year. Around 23 million visits to parks from Victorians involve physical activity which can provide further health benefits - estimated to be worth between $80-$200 million per annum. $600-$1,000 million per annum. Amenity value of Parks to adjacent residents is estimated at between $21-28 million per annum. Victoria's parks further provide social benefits through volunteering work in parks valued at $6 million per annum and park-related heritage valued at $6-23 million per annum.

Importantly, ecosystems also provide protective services against heatwave hazards (US EPA 2008, CoM 2014). For example, urban forest ecosystems reduce heat loads/stress experienced in neighbouring residential and commercial urban areas which in turn reduces risks to community health and peak electricity demand -

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[98] Ecosystem assets are spatial areas containing a combination of biotic and abiotic components and other characteristics that function together. In the SEEA: EEA, ecosystem assets are measured from two perspectives. First, ecosystem assets are considered in terms of ecosystem condition and ecosystem extent. Second, ecosystem assets are considered in terms of expected ecosystem service flows. In general terms, the capacity of an ecosystem asset to generate a basket of ecosystem services can be understood as a function of the condition and the extent of that ecosystem (DSE 2013).

[99] Ecosystem services are the contributions of ecosystems to benefits used in economic and other human activity. Three broadly agreed categories of ecosystem services are used: (i) provisioning services, (ii) regulating services and (iii) cultural services (DSE 2013).

[100] The condition of ecosystem assets within these park areas[100] is markedly higher than similar asset types managed (primarily by the 'private sector') outside of park areas (PV & DELWP 2015).

amongst other things. In this way, ‘ecosystem-based approaches’ are a notable (heatwave) adaptation response option for many of the productive and social sectors.

15.2 Nature of expected impacts

Extreme climate events such as heatwaves put stress on ecosystems and their component species. Species adjust to these stresses by occupying different climatic niches within the ecosystem (referred to as “buffering”) or - where a tipping point is reached – certain species can die off (mortality)[101]. These effects can in turn change the composition[102] and structure[103] of species (biodiversity) that make up a given ecosystem, and the flow of ecosystems services provided by these assets (Dunlop et al 2016).

Currently, there is not a sound understanding of how the composition and structure of Victorian ecosystem assets are affected by heatwave events (pers comms David Parkes, Dunlop et al 2016).

There has been some work on species-level impacts from heatwave hazards - for example mortality of bats, fertility of Zebra Finches, and impacts on Plane trees (CoM 2014). However, these effects have not been mapped to the ecosystem-level.

There has also been a study of the ecosystem-level impacts[104] from the full suite of climate parameter changes expected under future climate change - including heatwave parameters[105] (Dunlop et al 2016). This study generated some very important insights about the extent of overall impacts on ecosystems in Australia from climate change. These are discussed further in section 13.3 below.

However, due to the complex nature of ecological change[106] the study was not able to establish the details about how composition and structure of ecosystems is likely to change – or the changes attributable to heatwaves specifically[107]. This information is needed to assess impacts on the flow of ecosystem services.

The nature of heatwave impacts for the environment sector is broadly summarised in Table 40 below.

Table 40 Types of damages and losses expected in the environment sector

Damages	Losses
Damage to/transformation of ecosystem assets to undesirable states - where critical ecological functions degrade	Loss of ecosystem services (long-term)

Due to lack of information currently available on the biophysical (ecological) changes/impacts from heatwave events (in terms of ecosystem composition, structure, and function and how this will vary across regional partnership areas), a quantitative economic analysis is not undertaken for the environment sector.

The remainder of this chapter instead discusses environment sector vulnerability in qualitative terms.

Note, it could be possible to generate further indicative information on the biophysical impacts (e.g. “most likely” “worst case” and “best case” shifts in ecosystem types and corresponding geographical coverage/areas; % degradation in condition of each key ecosystem asset type) that could be used in a high-level economic

[101] Including through impacting fertility and reproduction cycles (e.g. timing).
[102] The type and relative proportions of species that make up an ecosystem.
[103] How species within an ecosystem interrelate.
[104] Strictly speaking, the CSIRO study looked at expected impacts on ‘biomes’. Biomes are a grouping of ecosystems that occur in similar climatic environments.
[105] maximum temperature during hottest month and solar radiation
[106] The CSIRO report states that “The different processes of ecological change, each driven by climate change, will combine to make prediction about the details of change and likely loss of biodiversity very difficult. As a result, managers will be faced with ongoing uncertainty about some aspects of the future changes to the systems they manage, and this will constrain the choice of options for managing biodiversity.”
[107] Increasing frequency and intensity of heatwaves are expected to be a key factor driving the *structural* changes in ecosystems;

assessment of ecosystem services loss. However, to generate this information would require intensive workshops with multiple ecological expert inputs – which is beyond the scope of this study.[108]

15.3 Sensitivity

Ecosystem asset types likely vary in their susceptibility to heatwave hazards. Key characteristics which make ecosystems relatively more susceptible to heatwave events are:

- *Environmental homogeneity*: Ecosystems that do not have much variation in environment (e.g. variation in topography) have less scope to "buffer" a heatwave event. For example, animal species within the ecosystem are less able to move to cooler micro-environments to mitigate heat stress.

- *Species richness and distribution*: Ecosystems that do not have much diversity in species (biodiversity), or where species do not have wide geographical distributions, have less scope to dynamically respond to heatwave stress. That is, ecosystems with less diversity will be less able to fill functional gaps left by movement or die-off of one species. This phenomenon is sometimes referred to as "biological buffering".

Susceptibility to heatwave stress also depends on the extent to which there are other stresses which are affecting a given ecosystem or its component species. For example, if a species is under stress from invasive alien species and is in poor population health, it is more likely to reach its tipping point from a heatwave event. Similarly, species exposed to disease and already in poor health are also likely to suffer more from a heatwave event.

Other climate-related stresses such as drought and bushfire also increase susceptibility of ecosystems to heatwave events. These stresses are expected increase in the future under the effects of climate change.

Dunlop et al (2016) assessed these cumulative/combined climate-change related stresses to be very significant for ecosystem assets in Australia, including in Victoria. The overall susceptibility of Victorian ecosystems from the combined effects of climate change is high and increasing (Dunlop et al 2016).

15.4 Extent of potential impacts

As mentioned above, there is currently a lack of detailed information on the biophysical (ecological) changes/impacts from heatwave events - in terms of ecosystem composition, structure, and function and how this will vary across regional partnership areas. This precludes an accurate understanding of the changes in ecosystem service flows expected from heatwave events and how these impacts will be distributed across geographical areas.

Nonetheless, it is still very informative to reflect on the high-level findings of the Dunlop et al (2016) study. This study found that the overall extent of ecosystem change (from the suite of climate parameters) across Australia is expected to be very high in the relative near term. By 2030, the combined effects of climate change are expected to cause around half the species within existing ecosystems to change. And by 2070, species composition - on average - is expected to change.

Table 41 below summarises these headline results.

[108] Dunlop et al (2016) suggests that accurate modelling of ecosystem change is "probably" only feasible at a "finer scale" (i.e. ecosystems in a given regional partnership area).

Table 41 Vascular-plant species composition change in Australia expected from climate change related stresses. The metrics vary from 0 (no change) to 1 ("completely different") (Dunlop et al 2016).

CLIMATE SCENARIO	BASED ON ANN MODELLING OF MAJOR VEGETATION GROUPS	BASED ON GDM MODELLING OF VASCULAR-PLANT SPECIES COMPOSITION
2030 Medium-impact	-	0.50±0.11
2030 High-impact	-	0.54±0.11
2070 Medium-impact	0.47±0.23	0.71±0.08
2070 High-impact	0.61±0.24	0.85±0.07

The Dunlop et al (2016) study further finds that:

- The rate of change of climate parameters/stresses is expected to be greater than the capacity of ecosystems to "buffer" stresses, leading to some species loss; and
- Due to the above, the overall condition of ecosystem assets – and flow of ecosystem services – is expected to substantially decline over the relative near term.

From the modelling, it appears that biophysical damage to ecosystem assets expected from (broader) climate change over the relative near term is potentially very substantial. Heatwaves are a material contributor to these climate change impacts.[109] Given the important contributions of environmental assets[110] to other sectors – particularly health, tourism, water, agriculture - these effects would be expected to have significant flow-through effects on the broader Victorian economy.

These impacts will likely be exacerbated in the future if key barriers currently constraining the capacity of the 'environment sector' are not addressed. Barriers are further discussed in section 15.5 below.

15.5 Barriers to effective adaptation

There are a wide range of barriers and impediments that constrain the capacity of individuals/businesses/Government to effectively manage heatwave risks to the environment. Select barriers that have been identified in this study for the environment sector are summarised in Table 42 below.

Table 42 Barriers constraining capacity of environment sector to adapt to heatwaves

i. Market failures	
Information gaps	There is currently a lack of scientific information and understanding about the biophysical (ecological) changes/impacts from heatwave events - in terms of ecosystem composition, structure, and function and how this will vary across regional partnership areas. This constrains ecosystem manager's ability to accurately assess risks and formulate targeted strategies to manage them (Dunlop et al 2016). It should be noted however, while there is uncertainty about details of ecological impacts, there is high confidence about many of the broader implications of climate change (e.g. that there will be major shifts in ecosystem composition and function). Many risk management options can be selected that are robust to the uncertainties (e.g. clearly worth doing irrespective of the details of future change), or increasingly relevant under increasing levels of change. Uncertainty is not a cause for inaction.

[109] increasing frequency and intensity of heatwaves are expected to be a key factor driving the *structural* changes in ecosystems;
[110] Through provision of ecosystem services.

'Public' nature of many ecosystem services	Many of the services provided by ecosystems have public good characteristics – meaning the enjoyment/use of the service by one person does not reduce amount available for another person (e.g. visual amenity of landscapes) and/or it is difficult to exclude members of the public from enjoying/using the service if they have not paid for it (e.g. air filtration services). These characteristics mean there are generally inadequate incentives for individuals or businesses (the private sector) to manage ecosystem assets to the level (extent or condition) that is socially optimal. This includes managing for heatwave risk.
'External' nature of some ecosystem services	Related to the public good concept identified above, some services provided by ecosystems are 'external' in nature. That is these benefits of these services 'spill over' to third parties. One example of this is the cooling effect (on urban areas) provided by forest ecosystems in urban areas. Where these are privately owned, the owners are not able to attract payment from neighbouring households or businesses for these cooling services. As a result, there is generally a lack of incentives for individual households/businesses to provide or adequately manage urban forest ecosystems – at least not to the level that is socially optimal. This includes provision of urban forest ecosystems as a "ecosystem-based" adaptation response.
ii. Governance and institutional arrangements	
Limited integration of heatwave risk into ecosystem /NRM planning processes (mainstreaming)	To date there has been only limited integration of heatwave risk into mainstream planning processes and plans – including at the Park level (Dunlop et al 2016). As a result, heatwave risk has not been systematically considered and managed by relevant institutions. Building local responses into core business is generally considered a better way to manage to heatwave risks to ecosystems (and climate change generally), rather than developing separate and standalone heatwave/climate change policies and plans (Dunlop et al 2016). Amongst other things, 'mainstreaming' helps to ensure these issues are given adequate policy/management attention alongside other competing priorities, the appropriate people are tasked with developing/implementing the risk response measures, and responses appropriately consider the local context. A key part of mainstreaming includes integration of heatwave risk into monitoring and evaluation frameworks to support learning for improvement (and adaptive management).
Capacity constraints for dealing with uncertainty	As mentioned above, there is high uncertainty around the biophysical (ecological) changes/impacts expected from heatwave events and climate change generally. This makes it more difficult to formulate appropriate adaptation/risk management strategies. Contributing to this difficulty is also a lack of capacity to appropriately incorporate uncertainty into policy analysis and decision-making (Dunlop et al 2016).[111]

15.6 Concluding remarks

The (biophysical) sensitivity of the environment sector to heatwave hazards specifically is not currently well understood. Available evidence suggests that ecosystem assets may be substantially degraded as a result of the suite of stresses (drought, heatwaves, fire etc) presented by climate change in the near-term future. By

[111] There is a need for more understanding about and better use of simple tools for helping planners and managers deal with uncertainty, for example, effective use of multiple scenarios where uncertainties are significant, as opposed to generating probabilities or probability distributions that are often appealing but very hard to interpret correctly (Dunlop et al, 2016).

2030, the combined effects of climate change are expected to cause around half the species within existing ecosystems to change (Dunlop et al 2016). Given the important contributions of environmental assets[112] to other sectors – particularly health, tourism, water, agriculture - these effects would be expected to have significant flow-through effects on the broader Victorian economy.

A focus of (heatwave-related) adaptation policy effort in the short-medium term should be on integrating consideration of heatwave risk – alongside other important climate risks - into mainstream (ecosystem management) planning and operational processes. This includes monitoring and evaluation to support learning and adaptive management, which is especially important in the context of high uncertainty. It also includes the development and utilisation of other policy analysis tools that practically integrate uncertainty.

Adaptation policy effort should also look at reducing barriers which constrain the adoption of 'ecosystem-based approaches' to managing climate risks to other sectors (e.g. urban forest ecosystems to reduce health and electricity sector impacts associated with the urban-heat-island effect). These barriers are cross-sectoral in nature and thus require cross-sectoral collaboration.

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[112] Through provision of ecosystem services.

Part D – Summary remarks and way forward

16 Priority sectors for future adaptation policy effort

The analysis documented in this study provides an **overview** of the nature and extent of heatwave vulnerability in Victoria and how this is spread across sectors and geographical areas. The analysis further provides some insight on the inter-linkages between sectors and how this plays out to influence heatwave vulnerability in other sectors.

Sectors and geographical areas that are themselves most vulnerable **and/or** which strongly contribute to vulnerability in other sectors are the ones where the heatwave 'problem' is considered greatest. These are the sectoral where adaptation policy effort by the Victorian State and Local Governments should be prioritised in the next two years.

Table 43**Error! Reference source not found.** provides a summary of sector vulnerability, contributions to vulnerability in other sectors, geographical distribution, and – based on these elements – provides a 'priority rating' for future adaptation policy effort (high, medium, or low priority). As outlined in this table, sectors assessed as high priorities are electricity, agriculture, construction, health, and environment. Substantial policy effort is already being allocated to the electricity sector.

Table 43 Summary analysis and recommendations for future adaptation policy effort

Sector	Vulnerability of sector (high, medium, low)[113]	Influences vulnerability in other sectors[114]	Geographical distribution	Priority rating (HIGH, medium, low)
Electricity	Low for current period Potentially high in near-term future	High	All regions	**HIGH**
Transport (rail & road)	Low	Medium	Primarily Melbourne metropolitan	Low to medium
Water	Quantitative estimates are low However, could be medium to high once damage to environmental assets are accounted for	High, especially for agriculture	All regions	Medium
Agriculture	High	Low	Wimmera Southern Mallee, Goulburn are shown to be proportionately most affected, but all non-metropolitan areas are vulnerable and should be included as part of	**HIGH**

[113] "High" is defined here as probability-weighted impacts for total sector greater than $20 million for current period. "Medium" is defined here as probability-weighted impacts between $5 million and $20 million for current period. "Low" is defined here as probability-weighted impacts less than $5 million for current period.

[114] This is expert judgement based on insights from sector analysis.

			future adaptation work.	
Construction	High	Low	Melbourne metropolitan	<u>**HIGH**</u>
Manufacturing	Medium	Low	Melbourne metropolitan	Medium
Mining	Low	Low	Gippsland and Loddon Campaspe are shown to be (proportionately) highly affected.	Low
Tourism	Quantitative estimates are Low But could be medium to high once damage to environmental assets are accounted for.	Low	Melbourne metropolitan and regions with key environmental assets	Medium
Health	Medium	High	All regions	<u>**HIGH**</u>
Environment	Potentially high	High, especially for water, tourism, agriculture, and health	All regions	<u>**HIGH**</u>

17 Focus of adaptation policy effort within and across sectors

Within the sectors that have been identified as high priorities, it is recommended that policy effort focus on addressing key barriers that are constraining the sectors' capacity to adapt to changing heatwave hazards. These barriers can be thought of as the causes and drivers of the heatwave vulnerability problem.

This study has undertaken brief desktop analysis as a starting point for this policy analysis work. Future policy analysis work can build on this, undertaking further primary research as needed.

Importantly this study identified several barriers that are cross-sectoral in nature[115]. These barriers, in general, appear to have received less attention within the traditional sector policy domains and will require increased coordination and collaboration across agencies to effectively address.

18 The need for meaningful monitoring and evaluation

An observation from the conduct of this study is there is very little monitoring and evaluation of heatwave risk (or climate-risk generally) being performed by State and Local Government Agencies as part of the implementation of 'normal' policies and plans. As a result, there has been minimal learning by Government over the last 5 to 10 years about heatwave risks that affect policy and how best to modify the design of policies (if at all) so they are heatwave-resilient and thus more effective at achieving their intended objectives. This is a key area for improvement.

For all sectors assessed in this study, is recommended that integration of heatwave risk into mainstream monitoring and evaluation be considered as a practical and effective entry point to mainstream climate risk considerations into policy making and decision-making processes. Amongst other things, monitoring data should provide for a more detailed sector impact analysis following future heatwave hazard events.

[115] For example:

- Split incentives in residential housing [health, urban environment, electricity].
- 'External' benefits of green urban design [health, urban environment, electricity].
- 'External' nature of (urban forest) ecosystem services [health, urban environment, electricity].
- 'External' benefits of distributed energy resources (e.g. rooftop solar photovoltaic and battery storage) [health, urban environment, electricity].

Appendix A – Climate and climate modelling

The Representative Concentration Pathways (RCP) used for this project were:

- RCP 4.5 (intermediate emissions) – emission reductions that stabilise the CO_2 concentration at about 540 ppm by 2100.
- RCP 8.5 (high emissions/business as usual) – minimal emission reduction and assumes increases in emissions leading to a CO_2 concentration at about 940 ppm by 2100.

The range of temperature change projected under each of the scenarios into the medium and long-term future is illustrated in Figure 29 below. As the temperature projections between RCP 4.5 and RCP 8.5 are similar in the near-term projection (2030), only one RCP scenario was reported in the risk assessments for this period.

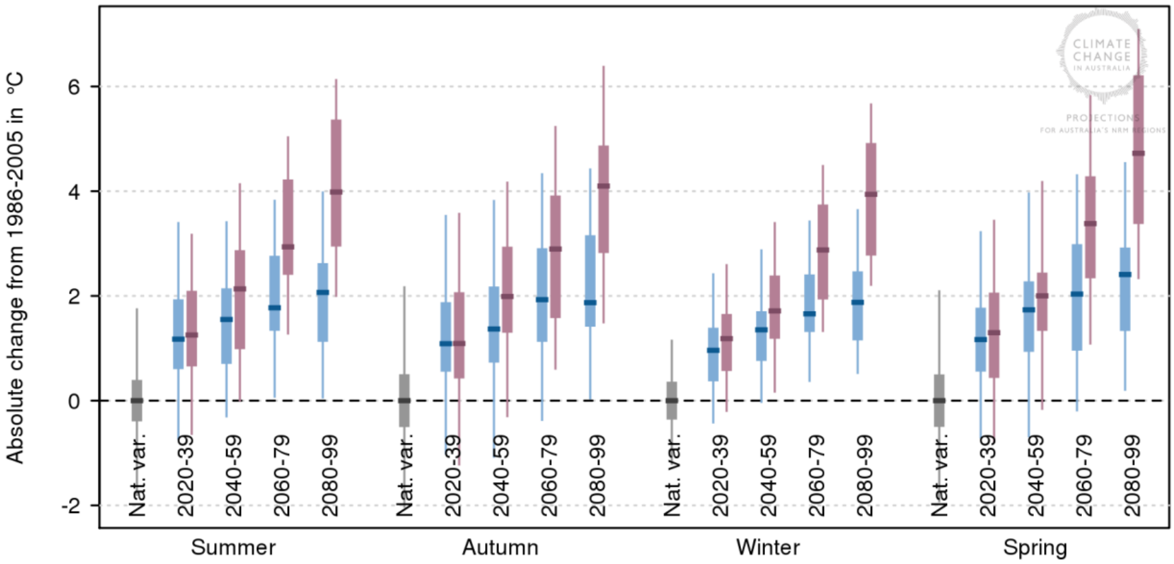

Figure 29 Range of temperature change between RCP scenarios. Note: minimal divergence in near term (2030) scenarios (CSIRO and BoM 2017).

The peak EHF threshold associated with each scenario, as well as the peak 2009 and 2014 events, at each weather station analysed is shown in Table 44.

Table 44 Peak EHF threshold for heatwave events based on current climate. The 2009 and 2014 event peaks are shown to provide context for the events and bold if the maximum EHF on record.

Scenario	Melb	Laverton	Cape Otway	Mt Gambier	NHill	Mildura	Kerang	Rutherglen	Wilsons Prom	East Sale	Orbost
Severe	25.4	15.8	25.3	30.1	28.6	24.7	9.7	18.8	19.9	17.0	19.2
Extreme	76.1	47.4	75.9	90.4	85.8	74.1	29.1	56.3	59.8	50.9	57.7
2009	122.0	**93.5**	85.4	116.8	**114.7**	56.7	84.6	54.5	**96.1**	**94.2**	**113.5**
2014	**136.0**	37.6	88.1	**128.3**	88.4	57.7	**98.2**	67.8	44.7	86.0	68.4
Very extreme	149.6	102.9	124.7	141.2	126.2	93.5	108.0	126.2	113.1	103.7	124.8

The current estimated return period for severe and extreme was calculated across the entire observed record and therefore may underestimate recent shifts in the climate.

Future climate

Analysis of future climate estimated the annual average days that EHF exceeded the threshold levels for each of the heatwave categories (i.e. severe, extreme and very extreme) across the 11 weather stations for each period 2030 and 2050. The results of this analysis for the whole of Victoria are summarised at Figure 30

Return periods for each of the heatwave events (severe, extreme, very extreme) at different points in time were then calculated using the estimated percentage change in annual average days ≥ the intensity threshold relative to the current baseline level.

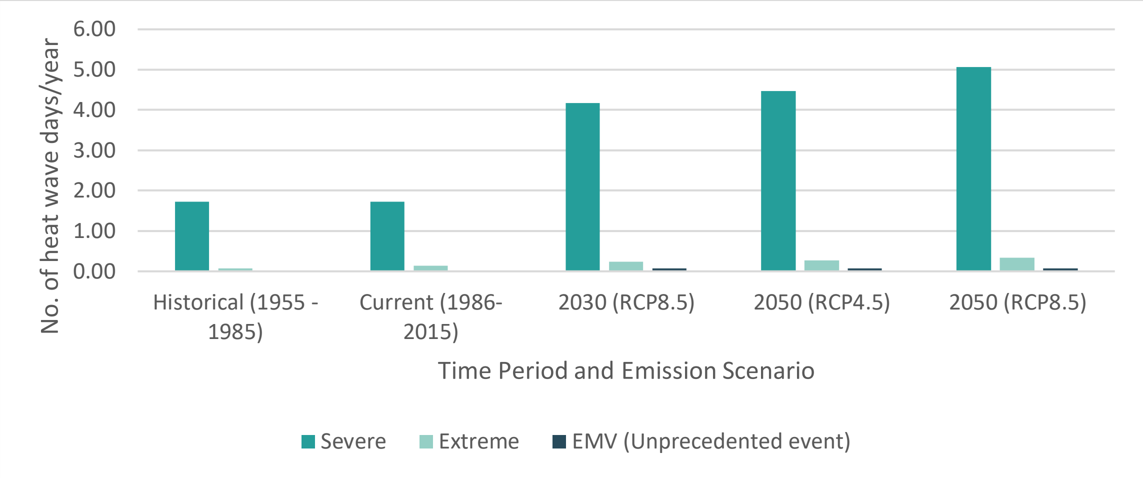

Figure 30 Annual average change in severe, extreme and very extreme heatwaves

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Appendix B – Regional Partnership Boundary Areas